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Houston Oxidant Modeling Study-1978
Volume III. Characterization of Data Quality

SRI International
Menlo Park, CA

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HOUSTON OXIDANT MODELING STUDY-1978
VOLUME III. CHARACTERIZATION OF DATA QUALITY

by

J. R. Martinez
Atmospheric Science Center
SRI International
Menlo Park, California 94025

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Project Officer

Basil Dimitriadis
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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ABSTRACT

During the period 15 September through 12 October 1978, the U. S. Environmental Protection Agency (EPA) conducted a special program that monitored air quality and meteorology in the Houston, Texas, area. The objectives of the program were to obtain a comprehensive data base suitable for use with photochemical air-quality simulation models and to provide a detailed body of data that can be used to investigate Houston's air quality in general and photochemical oxidants (HOMS Study) and aerosols (HACS Study) in particular.

The objectives of this study were (a) to evaluate the suitability of the 1978 Houston data base for photochemical modeling application, (b) to analyze spatial and temporal patterns of pollutant concentrations, (c) to archive data in a manner suitable for use with air quality simulation models, (d) to analyze and characterize the quality of the gaseous pollutant measurements, and (e) to use the data to evaluate the performance of the EKMA photochemical model. Results from the data evaluation and archiving work are reported in a three-volume report. Results from the EKMA evaluation work are reported in a separate report.

This report, Volume III of the three-volume report, covers the effort to analyze and characterize the quality of the gaseous pollutant measurements obtained in the 1978 HOMS Study. The analysis is based on data obtained in a number of field audits of the instruments used in the HOMS. The audits were performed independently by the EPA and by the Research Triangle Institute under the sponsorship of the EPA. The audit data were analyzed statistically to derive overall bounds for measurement accuracy and to define the accuracy and precision of individual instruments.

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SECTION 1

INTRODUCTION

OBJECTIVES AND BACKGROUND

This report describes the results of a study of the quality of the pollutant measurements made during the 1978 Houston Oxidant Modeling Study (HOMS). In the course of the HOMS, field audits were conducted to check the performance of the instruments that measured gaseous pollutants. In this study, the audit data will be analyzed to determine the accuracy and precision of the HOMS air quality data.

The HOMS was conducted from 15 September through 12 October 1978. Its primary objective was to obtain a data base suitable for use with photochemical air quality simulation models. The data base has been described in detail by Nitz and Martinez (1982). The air quality and meteorological data have been analyzed by Martinez et al. (1982). Descriptions of various aspects of the HOMS are found in the Proceedings of the Specialty Conference on Ozone/Oxidants (APCA, 1979).

REPORT ORGANIZATION

Section 2 reviews the procedures used to audit the instruments. The statistical analysis of the audit data is given in Section 3. Section 4 contains conclusions and recommendations.

SECTION 2

REVIEW OF AUDIT PROCEDURES

INSTRUMENTS AUDITED AND AUDIT SCHEDULE

Our concern is with the instruments that monitored the following gaseous pollutants:

- . Ozone (O_3)
- . Nitric oxide (NO)
- . Nitrogen dioxide (NO_2)
- . Oxides of nitrogen (NO_x)
- . Carbon monoxide (CO)
- . Total hydrocarbons (THC)
- . Methane (CH_4)
- . Sulfur dioxide (SO_2).

Field audits of these instruments were performed independently by two organizations: the U.S. Environmental Protection Agency (EPA), Region VI, and the Research Triangle Institute (RTI). RTI performed the audits under the sponsorship of the U.S. EPA Environmental Measurements and Support Laboratory. The results of the RTI audits have been described by Pasquini et al. (1978).

Table 1 lists the monitoring sites used during the HOMS and shows the site number and name, operating agency, variables measured at each site, and the UTM (Universal Transverse Mercator) coordinates of each monitoring site. Stations 10, 11, 15, and 16 were operated by private corporations that contributed their data to the HOMS; their instruments were audited in the same manner as the others. Monitoring at stations 13, 14, 21, 22, and 23 was done on a rotating schedule using two mobile laboratories, one operated by Radian Corporation for the EPA and the other operated by EPA itself. An instrumented aircraft operated by Washington State University (WSU) under contract to EPA was also used. In the discussions that follow, the locations of the various instruments are identified for the fixed monitoring stations. Instruments mounted in the Radian and EPA mobile laboratories and in the WSU aircraft are identified by operating agency, rather than by location.

TABLE 1. SITES FOR 1978 HOUSTON MONITORING PROGRAM *

Site No.	Site Name	Operating Agency	Parameters Measured	UTM Coordinates (m)
1	Aldine	Texas Air Control Board (TACB)	O ₃ , NO, NO _x , NO ₂ , SO ₂ , THC, CH ₄ , NMHC, CO, wind, temperature	275473E 3310112N
2	Mae Drive	TACB	Same as for Site 1, plus b _{scat} and detailed hydrocarbons	285303E 3295162N
3	Crawford	City of Houston	O ₃ , NO, NO _x , NO ₂ , THC, CH ₄ , NMHC, CO, detailed hydrocarbons, aldehydes	271648E 3293708N
4	Clinton	City of Houston	O ₃ , SO ₂ , THC, CH ₄ , NMHC, CO, TS, aldehydes	282382E 3291429N
5	Parkhurst	City of Houston	O ₃ , NO, NO _x , NO ₂ , THC, CH ₄ , NMHC, CO, detailed hydrocarbons, aldehydes	279100E 3303046N
6	Lang	City of Houston	O ₃ , NO, NO _x , NO ₂ , THC, detailed hydrocarbons	259960E 3301249N
7	Darlinghurst	City of Houston	O ₃ , THC	261000E 3281000N
8	Fuqua	City of Houston	O ₃ , NO, NO _x , NO ₂ , THC, CH ₄ , NMHC, CO, aldehydes	279296E 3278089N
9	Hornwood	EPA Region VI	O ₃	258000E 3289000N
10	Pasadena	Houston Light and Power (HLP)	O ₃ , NO, NO _x , SO ₂ , wind, detailed hydrocarbons, temperature, dewpoint	282000E 3289000N
11	Channelview	HLP	Same as Site 10 without detailed hydrocarbons	286000E 3295000N
12	Seabrooke	EPA	O ₃ , NO, NO _x , NO ₂ , detailed hydrocarbons	308000E 3276000N
13	Highlands	Radian Corporation	O ₃ , NO, NO _x , NO ₂ , SO ₂ , wind, temperature, dewpoint, solar radiation, CO, b _{scat} , aerosols	303000E 3301000N
14	Canino	EPA	NO, NO _x , NO ₂ , SO ₂ , CO, b _{scat}	263000E 3315000N
15	Westhollow	Shell Oil Co.	O ₃ , NO, NO _x , NO ₂ , wind, CO, dewpoint, temperature, solar radiation, detailed hydrocarbons	244323E 3294203N
16	Beasley	Monsanto	O ₃	216421E 3269082N
17	Pearland	Washington State University (WSU)	O ₃ , NO, NO _x , NO ₂ , CH ₄ , NMHC, CO, dewpoint, UV, wind, temperature, detailed hydrocarbons, freon, CCl ₄ , methylchloroform, pressure, pibal	280000E 3274000N
18	Sheldon	WSU	O ₃ , NO, NO ₂ , acoustic sounder, detailed hydrocarbons, wind, temperature, dewpoint, PAN	295000E 3308000N
19	Hobby	EPA	Same as Site 13	279700E 3280200N

TABLE 1 (concluded)

Site No.	Site Name	Operating Agency	Parameters Measured	UTM Coordinates (m)	
20	Jackrabbit	EPA	O ₃ , NO, NO _x , NO ₂ , PAN, SO ₂ , TS, THC, CH ₄ , NMHC, CO, b _{scat} , temperature, relative humidity, detailed hydrocarbons, freon, CCl ₄ , pressure, UV, VIS	252625E	3315675N
21	Alief	EPA	Same as Site 13 with UV but without CO	248600E	3289000N
22	Baytown	EPA	O ₃ , NO, NO _x , NO ₂ , SO ₂ , CO, b _{scat}	309000E	3295000N
23	Stude Park	EPA	Same as Site 13 with UV but without CO	269600E	3296700N
24	MacGregor	City of Houston	THC, wind, precipitation	268603E	3290782N
25	Radian Office	Radian Corp.	Pilot balloon	264780E	3298975N

*
O₃ data at sites 10, 11, 12, and NO, NO₂, NO_x data at sites 3, 4, 5, 6, 8, 12 were obtained with EPA instruments operated by Northrop Services, Inc. under contract to EPA.

Tables 2 through 7 list the instruments that monitored the various pollutants. The tables also show the date of each audit, the auditing organization, and the number of checks made during each audit. For ozone, Table 2 shows that 22 instruments were audited by either EPA or RTI or both from 26 September through 25 October. EPA audited 18 of the 22 instruments, with 10 being audited twice. All the EPA audits contain at least one audit performed near or after the end of the HOMS on 12 October. RTI audited all 22 instruments, but only once each; the RTI audits were performed from 26 September through 4 October.

The audit schedule for NO and NO_x instruments is shown in Table 3. Sixteen instruments were tested, 13 by EPA and all by RTI. The dates of these audits are the same as for ozone with the exception of EPA's audit at Parkhurst. As with ozone, EPA audited several instruments twice and RTI performed only single audits. The same pattern recurs in Table 4 for NO₂. In this case, 14 instruments were audited, with EPA auditing 10 and RTI all.

Table 5 contains the schedule for CO audits. Nine instruments were tested: EPA audited seven and RTI all nine. Only the Mae Drive instrument was audited twice by EPA. This is also the case in Table 6 for CH₄ and THC, which shows that seven instruments were audited by both EPA and RTI.

Only RTI audited SO₂ instruments. Seven instruments were audited; the schedule is shown in Table 7.

EXPERIMENTAL PROCEDURES

The audit procedure consisted of feeding a known concentration (henceforth called the reference concentration) of the gaseous pollutant to the instrument and recording the instrument's response. The reference concentrations usually included a zero level and several nonzero values. The number of reference concentrations used in each audit, including the zero level, was included in Tables 2 through 7.

Reference ozone concentrations were produced using an ultraviolet ozone generator. The EPA determined the reference ozone level using NBKI, whereas RTI established the reference concentration using gas phase titration. A detailed description of RTI's procedure has been given by Pasquini et al. (1978).

Test atmospheres of NO, NO_x, and NO₂ were generated by both EPA and RTI using standard-gas cylinder dilution and gas phase titration. The standard gases were referenced to NBS-SRM 1683 (RTI) and to NBS-SRM 1684 (both EPA and RTI). The EPA's standard-gas cylinder contained 94.1 ppm of NO. RTI used gases containing 44.7 ppm and 48.8 ppm NO (AIRCO certified cylinders FF 3782 and FF 1584, respectively).

Standard-gas cylinders were also used to generate reference concentrations of CO, CH₄, and SO₂. EPA used CO and CH₄ cylinders from Scott Environmental. RTI's cylinders contained 51.8 ppm and 54.0 ppm of CO, and 52.4 ppm and 52.0 ppm of CH₄. The standard SO₂ gases contained 53.1 ppm and 49.8 ppm of SO₂ in nitrogen.

Table 2
AUDIT SCHEDULE FOR OZONE

Location	Instrument	EPA		RTI	
		Date	Number of Audit Points	Date	Number of Audit Points
Aldine	MEC 1100	27 Sep.	5	27 Sep.	6
		16 Oct.	5		
Mae Drive	MEC 1100	28 Sep.	5	28 Sep.	6
		17 Oct.	5		
Crawford	MEC 1100	18 Oct.	5	26 Sep.	6
Clinton	MEC 1100	28 Sep.	5	27 Sep.	6
		19 Oct.	5		
Parkhurst	MEC 1100	29 Sep.	5	28 Sep.	6
		25 Oct.	5		
Lang	MEC 1100	3 Oct.	5	3 Oct.	5
		16 Oct.	4		
Darlinghurst	CSI 2000	2 Oct.	5	3 Oct.	6
		24 Oct.	5	--	-
Fuqua	MEC 1100	18 Oct.	5	29 Sep.	6
Hornwood	Bendix 8002	23 Oct.	5	30 Sep.	6
Pasadena	Bendix 8002	2 Oct.	5	2 Oct.	6
		12 Oct.	5		
Channelview	Bendix 8002	29 Sep.	5	29 Sep.	6
Seabrooke	Bendix 8002	13 Oct.	5	26 Sep.	6
Westhollow	MEC 1100	--	-	2 Oct.	6
Westhollow	Dasibi 1003AH	--	-	2 Oct.	6

Table 2 (concluded)

Location	Instrument	EPA		RTI	
		Date	Number of Audit Points	Date	Number of Audit Points
Beasley	Monitor Labs 8410	7 Oct.	5	3 Oct.	6
		19 Oct.	5		
Pearland	Bendix 8002	30 Sep.	5	30 Sep.	6
		12 Oct.	5		
Sheldon	CSI 2000	11 Oct.	5	4 Oct.	6
Jackrabbit	Bendix 8002	1 Oct.	5	30 Sep.	6
		11 Oct.	4		
Radian Mobile Lab	Meloy OA350	--	-	1 Oct.	6
EPA Mobile Lab	Bendix 8002	15 Sep.	5	1 Oct.	6
EPA Mobile Lab	Dasibi 1003AH	--	-	1 Oct.	7
WSU Aircraft	Bendix 8002	12 Oct.	5	2 Oct.	6
		TOTAL	138		132

Table 3
AUDIT SCHEDULE FOR NITRIC OXIDE AND OXIDES OF NITROGEN

Location	Instrument	EPA		RTI	
		Date	Number of Audit Points	Date	Number of Audit Points
Aldine	TECO 14	27 Sep.	5	27 Sep.	6
		16 Oct.	5		
Mae Drive	TECO 14	28 Sep.	5	28 Sep.	6
		17 Oct.	5		
Crawford	TECO 14	18 Oct.	5	26 Sep.	6
Parkhurst	Bendix 8101B	29 Sep.	4*	28 Sep.	5
		20 Oct.	5		
Lang	Bendix 8101B	3 Oct.	5	3 Oct.	6
		16 Oct.	5		
Fuqua	Bendix 8101B	18 Oct.	5	29 Sep.	6
Pasadena	CSI 1600	2 Oct.	5	2 Oct.	6
Channelview	CSI 1600	29 Sep.	5	29 Sep.	6
Seabrooke	Monitor Labs 8440	13 Oct.	5	26 Sep.	6
Westhollow	Monitor Labs 8440	--	-	2 Oct.	6+
Pearland	TECO 14	30 Sep.	5	30 Sep.	6
		12 Oct.	5		
Sheldon	Monitor Labs 8440	11 Oct.	5	4 Oct.	6
Jackrabbit	Monitor Labs 8440	1 Oct.	5	30 Sep.	6
		11 Oct.	5		
Radian Mobile Lab	CSI 1600	--	-	1 Oct.	6
EPA Mobile Lab	CSI 1600	--	-	1 Oct.	6
WSU Aircraft	Monitor Labs 8440	12 Oct.	5	2 Oct.	6
TOTAL			94		95

* 3 for NO_x, 4 for NO.

+ NO only.

Table 4
AUDIT SCHEDULE FOR NITROGEN DIOXIDE

Location	Instrument	EPA		RTI	
		Date	Number of Audit Points	Date	Number of Audit Points
Aldine	TECO 14	27 Sep.	5	27 Sep.	6
		16 Oct.	5		
Mae Drive	TECO 14	28 Sep.	5	28 Sep.	6
		17 Oct.	5		
Crawford	TECO 14	18 Oct.	5	26 Sep.	6
Parkhurst	Bendix 8101B	20 oct.	5	28 Sep.	5
Fuqua	Bendix 8101B	18 Oct.	5	29 Sep.	6
Pasadena	CSI 1600	12 Oct.	5	2 Oct.	6
Channelview	CSI 1600	29 Sep.	5	29 Sep.	6
Westhollow	Monitor Labs 8440	--	-	2 Oct.	6
Pearland	TECO 14	30 Sep.	5	30 Sep.	6
		12 Oct.	5		
Sheldon	Monitor Labs 8440	11 Oct.	5	4 Oct.	6
Jackrabbit	Monitor Labs 8440	1 Oct.	5	30 Sep.	8
		11 Oct.	6		
Radian Mobile Lab	CSI 1600	--	-	1 Oct.	6
EPA Mobile Lab	CSI 1600	--	-	1 Oct.	6
WSU Aircraft	Monitor Labs 8440	12 Oct.	5	2 Oct.	6
TOTAL			76		85

Table 5
AUDIT SCHEDULE FOR CARBON MONOXIDE

Location	Instrument	EPA		RTI	
		Date	Number of Audit Points	Date	Number of Audit Points
Aldine	Bendix 8200	16 Oct.	4	27 Sep.	8
Mae Drive	Beckman 6800	28 Sep.	3	28 Sep.	8
		17 Oct.	4		
Crawford	Beckman 6800	18 Oct.	4	26 Sep.	6
Clinton	Beckman 6800	19 Oct.	4	27 Sep.	6
Parkhurst	Beckman 6800	20 Oct.	4	28 Sep.	5
Westhollow	Beckman 886	--	-	2 Oct.	6
Pearland	Beckman 6800	12 Oct.	4	30 Sep.	5
Jackrabbit	Beckman 6800	11 Oct.	4	30 Sep.	6
EPA Mobile Lab	Aeronutronics Philco/Ford	--	-	1 Oct.	7
TOTAL			31		57

Table 6
AUDIT SCHEDULE FOR METHANE AND TOTAL HYDROCARBONS

Location	Instrument	EPA		RTI	
		Date	Number of Audit Points	Date	Number of Audit Points
Aldine	Beckman 6800	16 Oct.	4	27 Sep.	5
Mae Drive	Beckman 6800	28 Sep.	3	28 Sep.	5
		17 Oct.	4		
Crawford	Beckman 6800	18 Oct.	4	26 Sep.	6
Clinton	Beckman 6800	19 Oct.	4	27 Sep.	6
Parkhurst	Beckman 6800	20 Oct.	4	28 Sep.	5
Pearland	Beckman 6800	12 Oct.	4	30 Sep.	5
Jackrabbit	Beckman 6800	11 Oct.	4	30 Sep.	6
TOTAL			31		38

Table 7
AUDIT SCHEDULE FOR SULFUR DIOXIDE

Location	Instrument	RTI	
		Date	Number of Audit Points
Aldine	Bendix 5514548	27 Sep.	6
Mae Drive	Bendix 5514548	28 Sep.	6
Clinton	TECO 43	27 Sep.	6
Pasadena	Meloy SA-185	2 Oct.	6
Channelview	Meloy SA-185	29 Sep.	6
Radian Mobile Lab	Meloy 185	1 Oct.	6
WSU Aircraft	TECO 43	2 Oct.	8
		TOTAL	44

REFERENCE CONCENTRATIONS

Table 8 describes the reference concentrations used to audit the various instruments. The table lists the range, mean, standard deviation, median, and sample size of each concentration set.

For ozone, Table 8 shows that the EPA's reference levels span a narrower range than RTI's. Closer scrutiny of the data revealed that only 6 of the 132 reference levels in the RTI audits exceed 420 ppb. Hence, the EPA and RTI audits covered essentially the same concentration range. Although the means of the EPA and RTI sets for ozone are similar, comparison of the standard deviation and median indicates that the two distributions differ in shape and skewness. The standard deviation of the RTI data is larger than the mean largely because of the presence of the six concentrations that exceed 420 ppb, namely, 489, 500, 698, 703, 899, and 910 ppb. For the EPA set, about 19% of the reference levels had zero concentration, the corresponding figure being 17% for the RTI data.

The EPA and RTI reference concentrations of NO and NO_x show different ranges, and the other statistics indicate substantial dissimilarities in both the location and shape of the respective distributions. The EPA data have seven samples that exceed 450 ppb (viz., 467, 468, 468, 469, 469, 470, and 584), whereas the RTI data have 10 samples over 450 ppb (viz., 456, 458, 458, 481, 503, 505, 693, 698, 904 and 905). Approximately 20% of the EPA concentrations consisted of zeros; the corresponding figure for the RTI data is 17%.

Table 8 also indicates considerable differences between the EPA and RTI references for NO₂. However, the differences in the range are less pronounced than they appear to be because only four of the RTI samples exceed 490 ppb (viz., 690, 690, 880, and 890). Zero concentrations accounted for about 20% of the EPA data, and for about 17% of the RTI concentrations.

The EPA and RTI reference levels for CO also display marked differences in their statistical descriptors in Table 8. The EPA did not include zero concentration in its audits. In fact, the EPA's reference concentrations consisted of only four distinct values: 5.3, 20.4, 30.3 and 45.6 ppm; there were eight samples for each of the first three of these, and seven samples for 45.6 ppm. By contrast, the RTI references spanned a wider concentration range: about 39% of the values are below 5.3 ppm (including 18% zero concentration). Thus, the RTI audits provided a fuller test of the instruments at the low end of the concentration range.

THC and CH₄ also have different distributions of reference concentrations for the EPA and RTI data. As with CO, the EPA data exclude zero concentration, but the RTI data do not. Moreover, the RTI range is more than twice as wide as the EPA's. The EPA concentrations consisted of four values: 1.0, 4.4, 6.3, and 9.4 ppm, the first three having eight samples each, and the last, seven. By contrast, the RTI levels were regularly distributed between 0 and 10.0 ppm, the six samples above 10.0 ppm being 13.7, 14.4, 14.9, 17.0, 17.4, and 18.4 ppm.

Table 8

REFERENCE CONCENTRATIONS

Species	EPA				RTI			
	Range	Mean	Standard Deviation	Sample Size	Range	Mean	Standard Deviation	Sample Size
Ozone [*]	0 - 420	168.7	128.9	138	0 - 910	165.5	171.7	132
NO and NO _x [*]	0 - 584	186.7	153.6	94	0 - 905	203.0	194.6	95
NO ₂	0 - 355	139.7	115.7	76	0 - 890	188.1	196.2	85
CO ⁺	5.3 - 45.6	24.7	14.7	31	0 - 40.9	11.4	12.1	57
THC and CH ₄ ⁺	1.0- 9.4	4.9	3.4	31	0 - 18.4	6.1	5.4	38
SO ₂ [*]	--	-	-	-	0 - 1050	273.9	247.7	44

Note: Dashes denote no audit performed.

^{*} Units are parts per billion (ppb).

⁺ Units are parts per million (ppm).

Table 8 shows SO₂ data only for RTI because the EPA did not audit SO₂ instruments, as noted earlier.

It is evident from Table 8 that there are substantial differences between the concentrations used by the EPA and RTI to conduct the audits. In particular, the concentrations cover different ranges, and their distributions also differ within the range spanned.

SECTION 3

STATISTICAL ANALYSIS OF AUDIT DATA

METHODOLOGY

The statistical analysis of quality assurance audit data from the HOMS includes: (1) obtaining frequency distributions for percent relative error (percent relative error = $100 \times [\text{measured} - \text{reference}]/\text{reference}$); and (2) performing regression analyses of measured and reference concentrations for individual instruments. The analysis was performed separately for the EPA and RTI data because of the differences in their audit procedures.

The audit data have been analyzed in two ways. One type of analysis examines the total variation of measurement errors for each variable (e.g., ozone) by aggregating the data for all the instruments. This allows us to investigate the error distribution and to estimate overall bounds of measurement error. Although these error bounds do not necessarily apply to a specific instrument at a particular time, they quantify the size and frequency of the errors likely to be found in the totality of measurements. Aggregating the audit data also provides an easy way to identify large errors and possible anomalies.

The second analysis considers each instrument individually, using regression techniques to define the relationship between measured and reference concentrations.

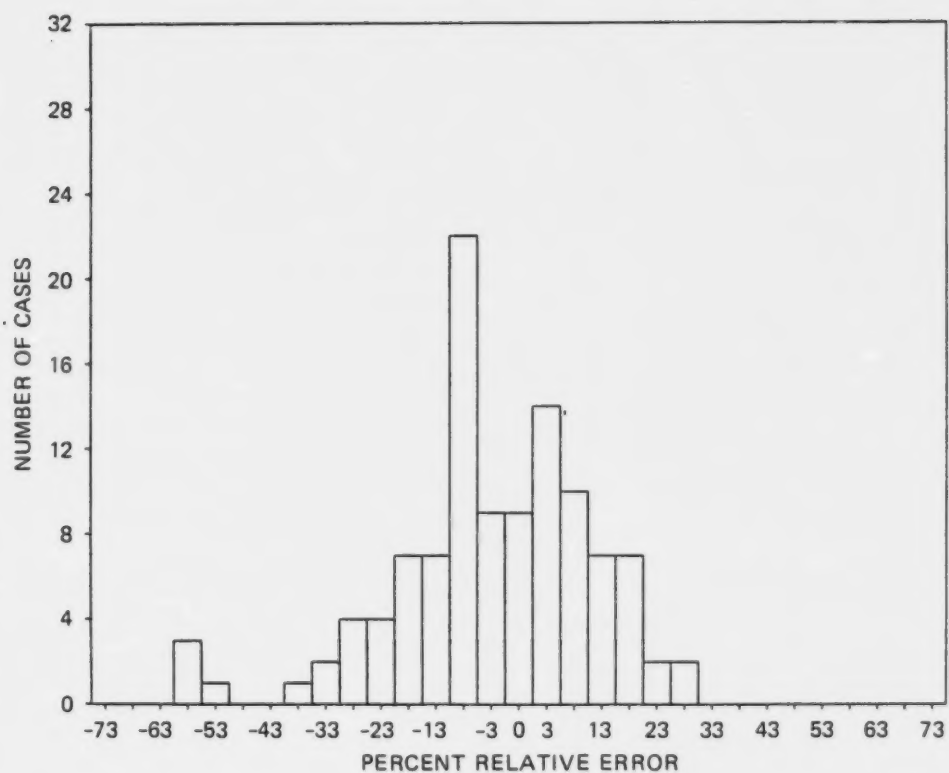
In what follows, the O₃, NO, NO_x, and NO₂ audits for the Jackrabbit site will be treated as special cases because the nominal concentration of the calibration gas was subsequently found to be incorrect (personal communication from W. Lonneman, 1980; Nitz and Martinez, 1982).

ESTIMATION OF OVERALL ERROR BOUNDS

Ozone

Figures 1 and 2 show histograms of percent relative error for the aggregated O₃ data for the EPA and RTI data sets, respectively, excluding the Jackrabbit instrument. The bar labeled 0 represents the number of cases where no error was detected. The other bars represent a 5% error interval, the number label of the bar being the center of the interval. For example, the bar labeled 3 represents the interval 1% to 5%.

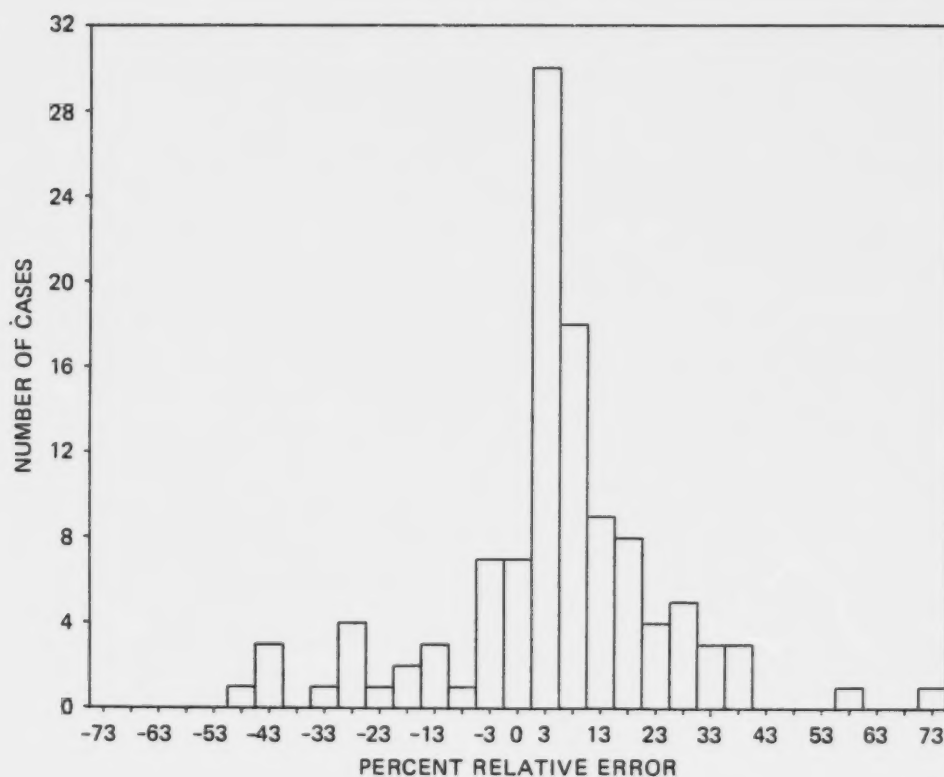
Comparing Figures 1 and 2 shows that the EPA audits tended to yield negative errors more frequently than the RTI tests. It is also apparent



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FIGURE 1 HISTOGRAM OF PERCENT RELATIVE ERROR FOR EPA OZONE AUDITS

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



HA-7938-2

FIGURE 2 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI OZONE AUDITS

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

that small errors are less frequent in the EPA than in the RTI data. Thus, the EPA data have about 29% of the errors within the $\pm 5\%$ band, whereas the RTI data have about 39%.

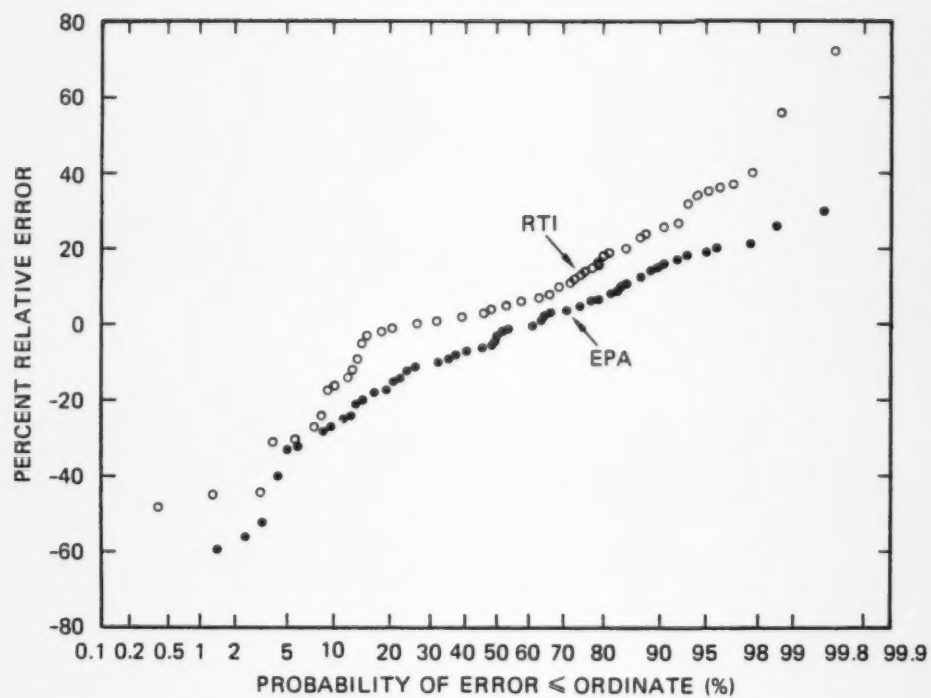
Figure 1 shows four errors in the range -51% to -60%; all occurred at the Channelview site. The RTI audits also detected substantial errors in the Channelview measurements, the errors being -27%, -44%, -46% and -48%. This suggests that this instrument was not working properly, and that its O₃ data should be adjusted to reduce the negative bias. However, both the EPA and RTI audits of the Channelview O₃ monitor were performed the same day (29 September 1978), which raises the possibility that the negative bias could be a short-term anomaly. In this study, we have no means of resolving this problem and recommend that the records of routine calibrations of the Channelview instrument be examined to determine whether a long term bias exists. (Lonneman (personal communication, 1982) has informed us that Northrop Services Inc. has examined the calibration data and that it appears that the large errors detected at the Channelview O₃ monitor were a short-time anomaly.)

The RTI audits (Figure 2) show one case of a 72% error. This error was detected at the Aldine instrument during an audit conducted on 27 September 1978. Other errors detected during the same audit ranged from 34% to 41%. By contrast, the EPA audit performed the same day measured errors in the range 19% to 26%. Hence, it appears that on that day the O₃ monitor at Aldine was biased positively, but the magnitude of the error is uncertain. A second audit of the Aldine instrument conducted by EPA on 16 October 1978 measured negative errors in the range -5% to -10%. Both EPA audits revealed a very high linear correlation between measured and reference concentration, which was not the case for the RTI audits. Thus, the EPA audit data appear to be more internally consistent than RTI's, and probably are better indicators of the condition of the Aldine ozone instrument.

Figure 3 compares the cumulative frequency distribution of percent relative error for the RTI and EPA data. The RTI distribution is irregular and can hardly be considered Gaussian. The distribution of the EPA data more closely resembles a Gaussian distribution for probabilities exceeding 5%. The RTI distribution is above the EPA's because positive errors occur more frequently in the former than in the latter.

Table 9 shows various statistics of the distribution of percent relative error for the EPA and RTI data. The two means have opposite signs, and their difference is statistically significant at the 0.05 level. Given that both agencies audited the same instruments, it seems reasonable to conclude that differences in the audit procedures account for the discrepancy in the sign of the means. Nevertheless, both agencies reported nearly equal percentages of audits with relative errors in the range of $\pm 10\%$. Both data sets indicate that at least 75% of all the audits fell within the $\pm 20\%$ error band.

For Jackrabbit, the ozone audits (as well as the NO, NO₂, and NO_x audits) were adjusted to correct a scaling error caused by a mislabeling of the calibration gas. The label showed a concentration of 108 ppm, but the



HA-7938-3

FIGURE 3 CUMULATIVE FREQUENCY DISTRIBUTION OF PERCENT RELATIVE ERROR FOR OZONE AUDITS

Table 9
STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR OZONE MEASUREMENTS*

<u>Statistic</u>	<u>Audit Agency</u>	
	<u>EPA</u>	<u>RTI</u>
Mean	-4.6	5.4
Standard deviation	16.9	18.6
Median	-3.0	5.0
Percent of audits within <u>+10%</u> error band	57.7	56.3
Percent of audits within <u>+20%</u> error band	82.9	75.9
Percent of audits within <u>+30%</u> error band	93.7	88.4

* Excluding Jackrabbit's.

actual concentration was subsequently found to be 85 ppm (Lonneman, 1980). Consequently, the measurements (but not the reference concentrations) were scaled by a factor of 85/108. (This was also done to all the O_3 , NO , NO_x , and NO_2 data for Jackrabbit in the HOMS archive; cf. Nitz and Martinez, 1982.) After correction, the EPA audits showed relative errors ranging from -21% to +6%, whereas the errors in the RTI audits ranged from -24% to -1%. Thus, duly adjusted, the relative errors of the Jackrabbit audits fell well within the error range of the other ozone instruments.

Summarizing, the ozone audits indicate that between 75% and 80% of the measurements can be characterized as being accurate to within +20%.

NO , NO_x , and NO_2

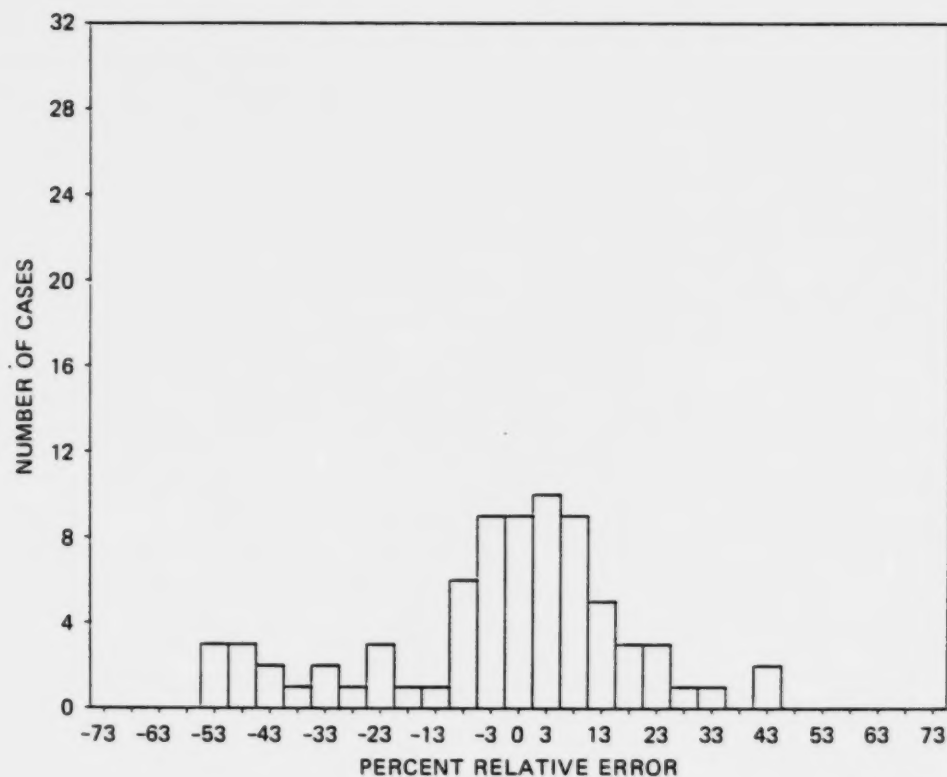
For NO , histograms of percent relative error for the aggregated EPA and RTI data (except the Jackrabbit data) are shown in Figures 4 and 5, respectively. It is apparent that EPA's audits (Figure 4) show a flatter, more spread out distribution than RTI's (Figure 5).

For both data sets, the largest positive errors were between 41% and 42%, and were detected at the Parkhurst site in audits conducted on consecutive days (see Table 3). Hence, it is apparent that on those days the Parkhurst instrument had a substantial positive bias. A second audit by EPA several days later showed relative errors ranging from 6% to 8%, indicating that the large positive bias had been corrected.

The largest negative errors in the EPA audits ranged from -39% to -55%, and were observed at the Pearland and Fuqua instruments. The former had errors of -39%, -43%, -52%, and -55%, and the latter, -45%, -46%, -47%, and -49%. By contrast, the RTI audits of these two instruments, which were not performed on the same days as the EPA audits, showed much lower errors ranging from 0% to 5% for Fuqua, and from -4% to 10% for Pearland. The discrepancy between these data may be indicative of erratic response at these two instruments.

The largest negative error in the RTI data for NO was -34%, and was detected in the instrument mounted in the WSU aircraft. The RTI audits of this instrument showed the errors ranging from -17% to -34%. EPA audits conducted 10 days later detected errors ranging from -19% to -30%. Thus, it appears that the WSU instrument had a substantial negative bias.

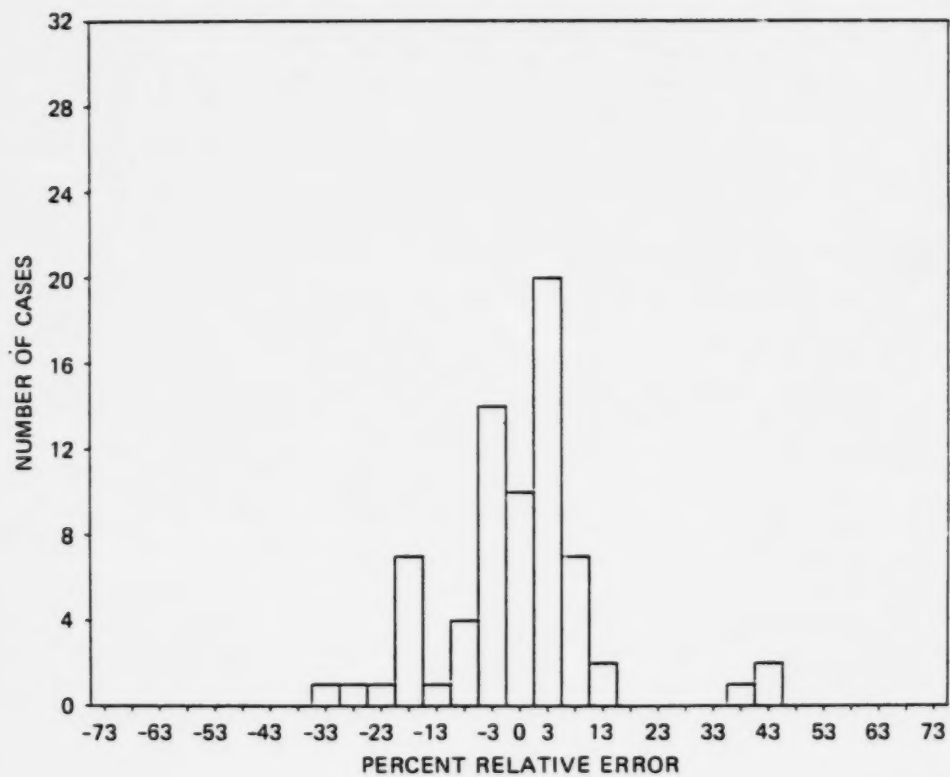
Table 10 shows the statistics of the error distribution for the NO instruments. The difference between the two means is not statistically significant at the 0.05 level. However, the RTI data are tightly clustered about zero, with about 85% of the points falling within the +20% error band. By contrast, the distribution of the EPA data has long tails, and only about 71 percent of the errors are bounded by +20%. As with ozone, the EPA audits for NO continue to show a negative bias, but the RTI audits show a positive bias.



HA-7938-4

FIGURE 4 HISTOGRAM OF PERCENT RELATIVE ERROR FOR EPA AUDITS OF NITRIC OXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



HA-7938-5

FIGURE 5 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF NITRIC OXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

Table 10

STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR NITRIC OXIDE MEASUREMENTS*

<u>Statistic</u>	<u>Audit Agency</u>	
	<u>EPA</u>	<u>RTI</u>
Mean	-3.6	0.39
Standard deviation	21.6	12.4
Median	0.0	0.0
Percent of Audits within <u>+10%</u> error band	57.3	74.7
Percent of Audits within <u>+20%</u> error band	70.7	84.8
Percent of audits within <u>+30%</u> error band	81.3	94.9

*Excluding Jackrabbit's.

After adjustment, the Jackrabbit instrument's NO data showed relative errors ranging from -6% to -2% for the EPA data, and from -13% to -4% for the RTI data. Both ranges are well within the bounds shown in Table 10.

To summarize, the analysis indicates that between 70% and 85% of the NO measurements are accurate to within 20%.

Histograms of the percent relative error observed in the audits of NO_x instruments are shown in Figures 6 and 7 for the EPA and RTI data, respectively. Figure 6 shows that the EPA data include four cases in the range of -46% to -50%. These were detected at the Fuqua instrument, which, as noted above, also produced large negative errors for NO. The NO_x audits for the Pearland instrument had errors ranging from -10% to 0%, which contrasts with the much larger negative errors detected for NO. Thus, at Pearland the NO_x data quality appears to be better than that for NO.

As with NO, the EPA and RTI data are consistent in indicating that the Parkhurst instrument had errors ranging from 32% to 35% for NO_x. Hence, this instrument had a large positive bias for both NO and NO_x.

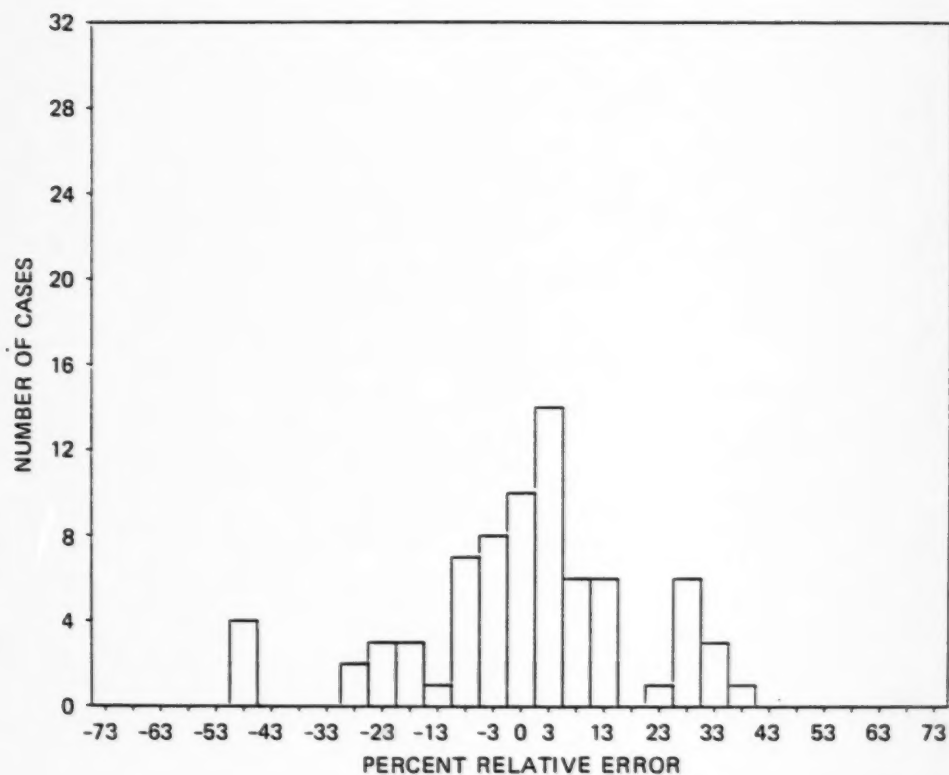
In contrast to Figure 6, Figure 7 shows that the RTI audits detected no large negative errors. The cluster of positive errors centered at 33% corresponds to the Parkhurst instrument, as noted above. Not shown in Figure 7 is one very large positive error of 94% detected in the NO_x instrument of the WSU aircraft. The errors of the five points of the WSU instrument's audit were 94.2%, 5.7%, -6.4%, -7.3%, and -8.5%. Thus, the 94.2% error is anomalous; we do not know whether the data are correct, or whether the instrument malfunctioned for that point and was subsequently adjusted for the remainder of the audit. The RTI audit of this instrument is not consistent with the EPA audit, which contains errors ranging from -26% to -15%.

Statistics of the error distribution for the NO_x audits are shown in Table 11. Table 11 follows the pattern of Table 10 for NO: RTI's distribution is more tightly clustered about zero than the EPA's. Also, the difference between the means is not statistically significant at the 0.05 level. The mean value of the RTI distribution is heavily influenced by the large 94.2% error; removing this point from the data set reduces the mean value to 1.0%.

The Jackrabbit NO_x audits (after adjustment) revealed errors in the range -21% to -1% for the EPA data, and from -4% to -2% for the RTI audits. Both these ranges are consistent with the ranges of the other instruments.

Overall, the audits reflect an accuracy of the NO_x measurements that is somewhat better than for NO. For NO_x, between 70% and 89% of the measurements can be characterized as being accurate to within 20%, and at least 90% have +30% accuracy.

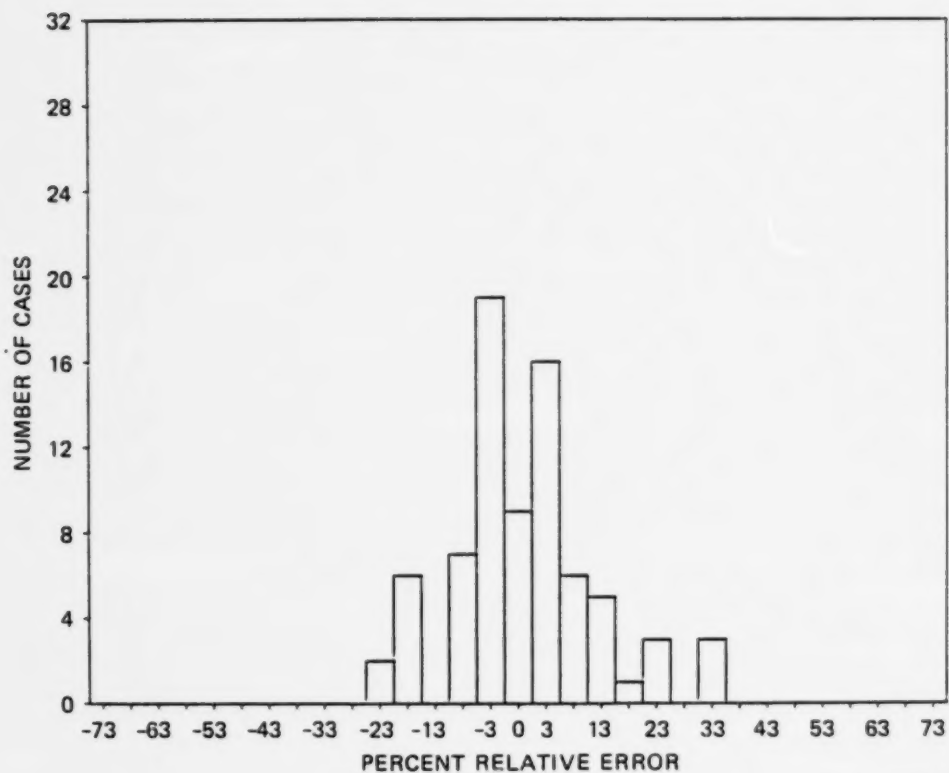
Figures 8 and 9 display histograms of percent relative error for the NO₂ audits conducted by EPA and RTI, respectively. It is apparent once again that the two error distributions are quite different. The EPA data



HA-7938-6

FIGURE 6 HISTOGRAM OF PERCENT RELATIVE ERROR FOR EPA AUDITS OF NITROGEN OXIDES

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



HA-7938-7

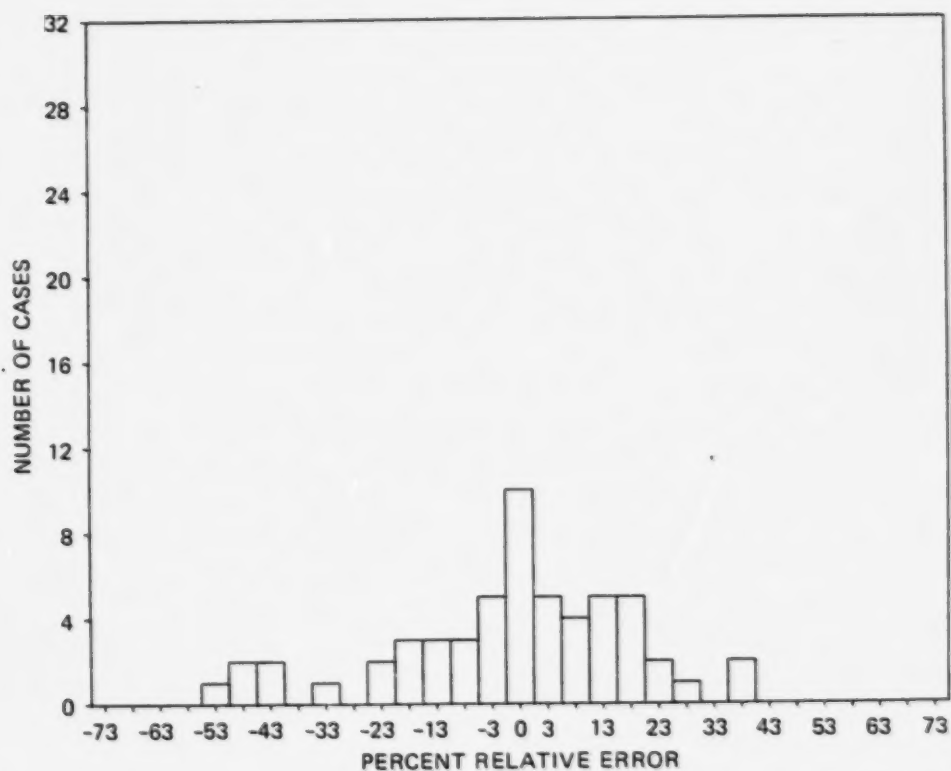
FIGURE 7 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF NITROGEN OXIDES

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

Table 11
STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR NO_x MEASUREMENTS*

Statistic	Audit Agency	
	EPA	RTI
Mean	0.67	2.2
Standard deviation	18.5	15.4
Median	0.0	0.0
Percent of audits within <u>+10%</u> error band	60.0	73.1
Percent of audits within <u>+20%</u> error band	73.3	88.5
Percent of audits within <u>+30%</u> error band	89.3	94.9

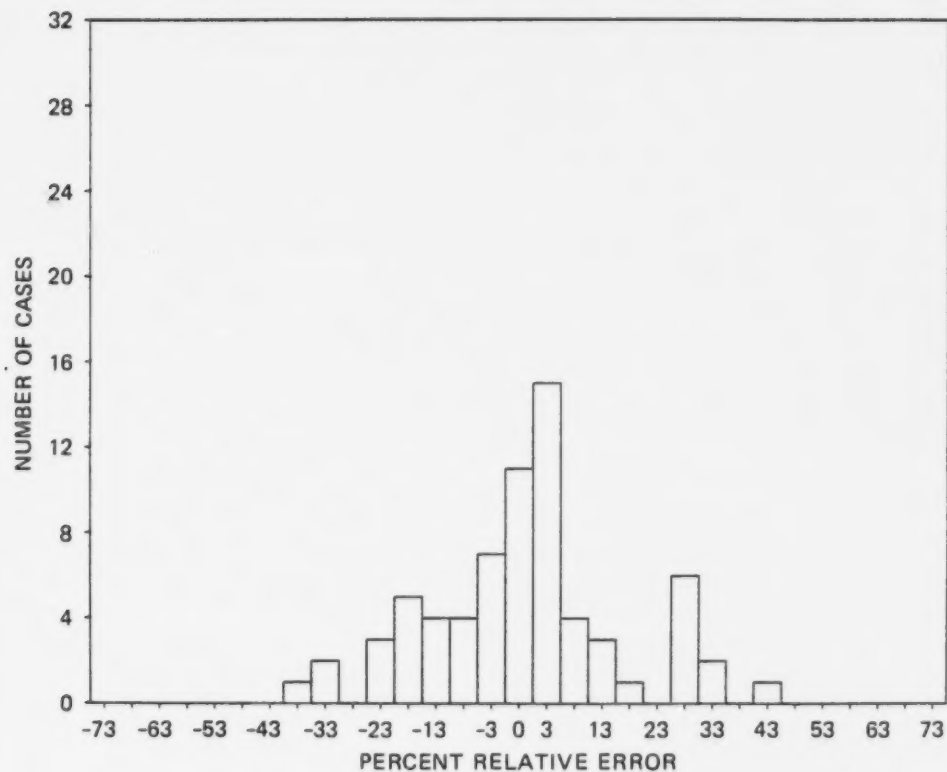
*Excluding Jackrabbit's.



HA-7938-8

FIGURE 8 HISTOGRAM OF PERCENT RELATIVE ERROR FOR EPA AUDITS OF NITROGEN DIOXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



HA-7938-9

FIGURE 9 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF NITROGEN DIOXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

have a relatively flat distribution with larger negative errors than the RTI data, which are clustered in the neighborhood of zero error. Five cases with large negative errors are present in the EPA data; they range from -43% to -54%. Four of the cases (with errors between -43% and -46%) occurred at the Fuqua instrument; this is consistent with previous findings for NO and NO_x. The case with -54% error occurred at the Pasadena instrument; four other points in the audit of this instrument showed errors ranging from -33% to -16%. The Pasadena instrument was audited by RTI on the same day as the EPA audit, and found errors ranging from -79% to -14%. Hence, NO₂ audits at Pasadena showed a substantial negative bias.

The EPA data also contain a very large positive error of 182.2% that is not shown in Figure 8. This error was detected at the Pearland instrument; other errors during the same audit were -2.3%, 10.8%, and 36.4%. Recall that Pearland also displayed several large negative errors for NO, and that NO_x errors were smaller. Hence, the NO and NO₂ readings at Pearland were less accurate than NO_x measurements on the day of the audit. Audits of NO₂ conducted at Pearland by both EPA and RTI showed much smaller errors ranging from -7% to +13%. Thus, the error condition at Pearland was probably not chronic.

The RTI audits contained two large errors not shown in Figure 9. A large error of -79% detected at the Pasadena instrument was discussed above. The second large error had a value of 115.5%, and was detected at the WSU aircraft. Other errors for the WSU instrument were -3.8%, 0.%, 0.3%, 7.9%, and 27.8%. Hence, the 115.5 percent error is anomalous; it is akin to the 94.2% error detected in the audit of the NO_x instrument of the WSU aircraft. Thus, whatever affected NO_x seems to have influenced NO₂ also.

Statistics of the error distribution for NO₂ are shown in Table 12. The means and medians are equal. The larger spread of the EPA distribution is reflected in the larger standard deviation and in the smaller percentage of cases within the $\pm 10\%$ error band. However, both distributions have about the same percentage of cases within the $\pm 20\%$ band.

For Jackrabbit, after adjustment the NO₂ audits performed by the EPA had errors in the range -28% to +12%, and RTI's -21% to +4%. These errors are well within the error range of the other instruments.

Table 12 indicates that, taken together, about 75% of the NO₂ measurements can be considered to be accurate to within $\pm 20\%$; perhaps up to 90% are accurate to within $\pm 30\%$.

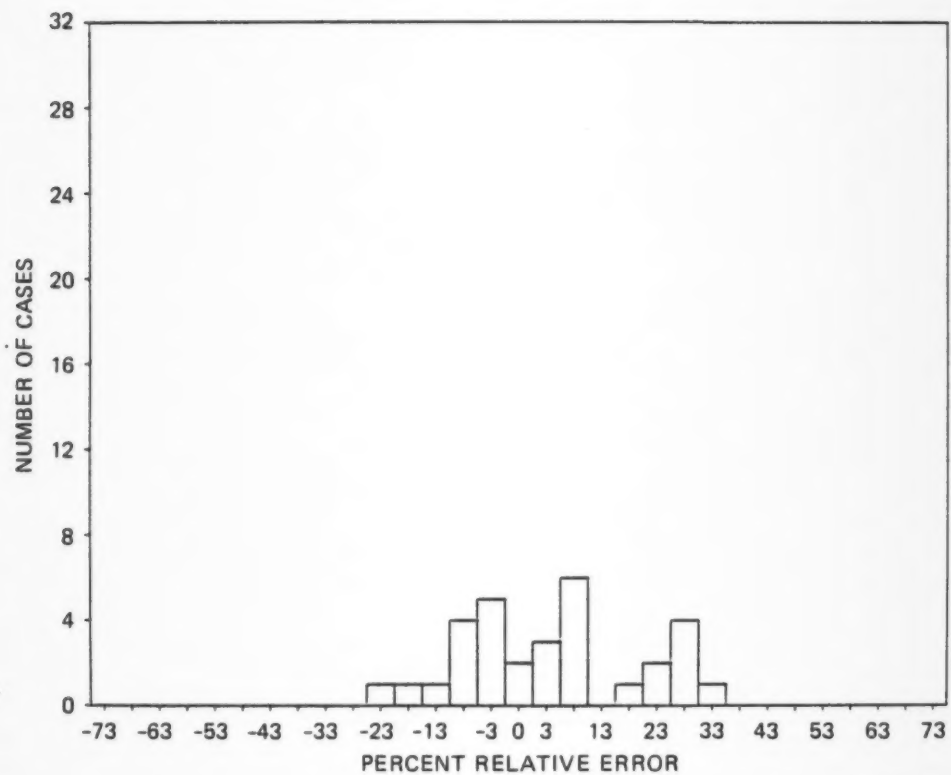
Carbon Monoxide

Figures 10 and 11 display histograms of percent relative error for the EPA and RTI audits, respectively. The figures show that the EPA audits detected a positive bias while the RTI audits indicate a negative bias in the CO measurements. The figures also show that large errors are less prevalent in the EPA's audits (Figure 10) than in RTI's (Figure 11).

Table 12
STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR NO₂ MEASUREMENTS*

Statistic	Audit Agency	
	EPA	RTI
Mean	1.4	1.4
Standard deviation	31.3	22.9
Median	0.0	0.0
Percent of audits within <u>+10%</u> error band	47.4	57.7
Percent of audits within <u>+20%</u> error band	75.4	76.1
Percent of audits within <u>+30%</u> error band	84.2	88.7

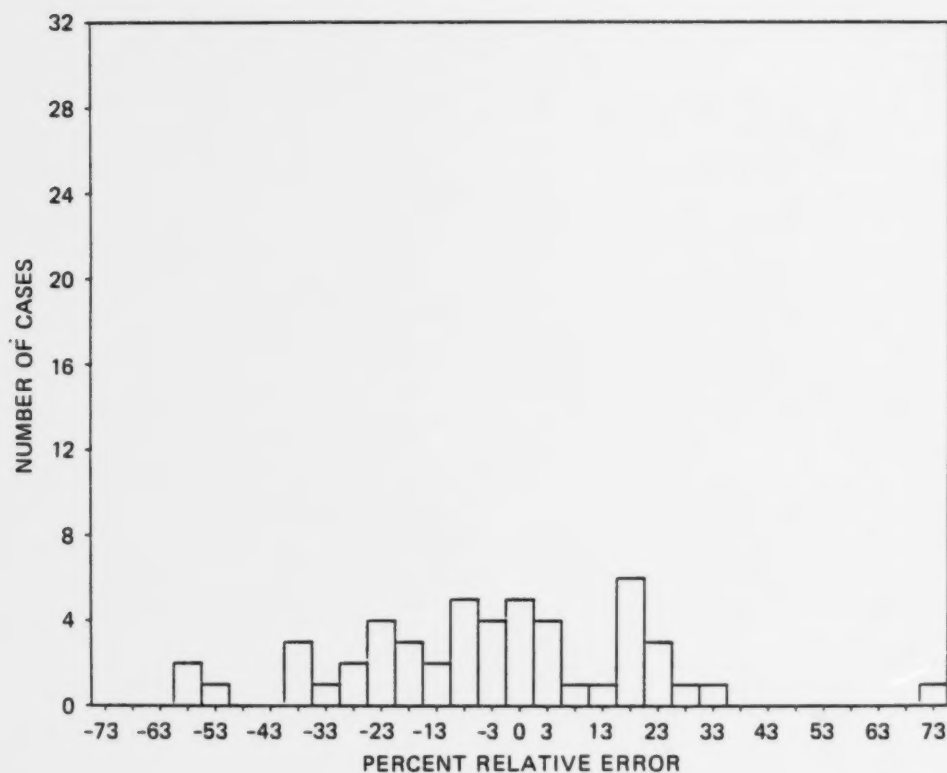
* Excluding Jackrabbit's.



HA-7938-10

FIGURE 10 HISTOGRAM OF PERCENT RELATIVE ERROR FOR EPA AUDITS OF CARBON MONOXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



HA-7938-11

FIGURE 11 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF CARBON MONOXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

The RTI audits include the largest errors. The largest negative errors ranged from -60% to -53%, and were detected at the EPA mobile laboratory. This audit included five nonzero reference concentrations, and the errors were -60%, -58%, -53%, -23%, and +5%. Two other points in the audit had zero reference concentration and recorded positive zero-drifts of 1.75 and 3.0 ppm. Thus, this instrument was not properly adjusted when it was audited.

The largest positive error in the RTI data was 71%, and was detected at the Jackrabbit instrument. For this audit, the errors were 18%, 19%, 20%, 22%, and 71%. An EPA audit performed 11 days later showed errors ranging from 19% to 26%. It is apparent that this instrument was biased positively at the time of the audits.

Table 13 shows statistics of the error distributions. The difference in the frequency of positive and negative errors is reflected in the opposite signs of mean and median. Moreover, the difference between the two means is statistically significant at the 0.05 level. About 74% of the EPA audits fall within the $\pm 20\%$ error band, compared to only 62% for the RTI audits.

The audit data suggest that 60% to 70% of the audits, and presumably the regularly-collected data as well, can be characterized as being accurate to within $\pm 20\%$. The audits also indicate that relative errors greater than 50% occur occasionally.

Methane and Total Hydrocarbons

Histograms of percent relative error for the EPA and RTI audits of CH_4 instruments are shown in Figures 12 and 13, respectively. As was the case with CO , the EPA audits indicate a tendency toward a positive bias and the RTI audits the opposite. Neither data set includes large errors.

Table 14 shows the statistics of the error distributions for the CH_4 audits. As indicated by Figures 12 and 13, means and medians have opposite signs. The difference between the means is statistically significant at the 0.05 level. The table shows that between 85% and 90% of the audits fall within the $\pm 20\%$ error band.

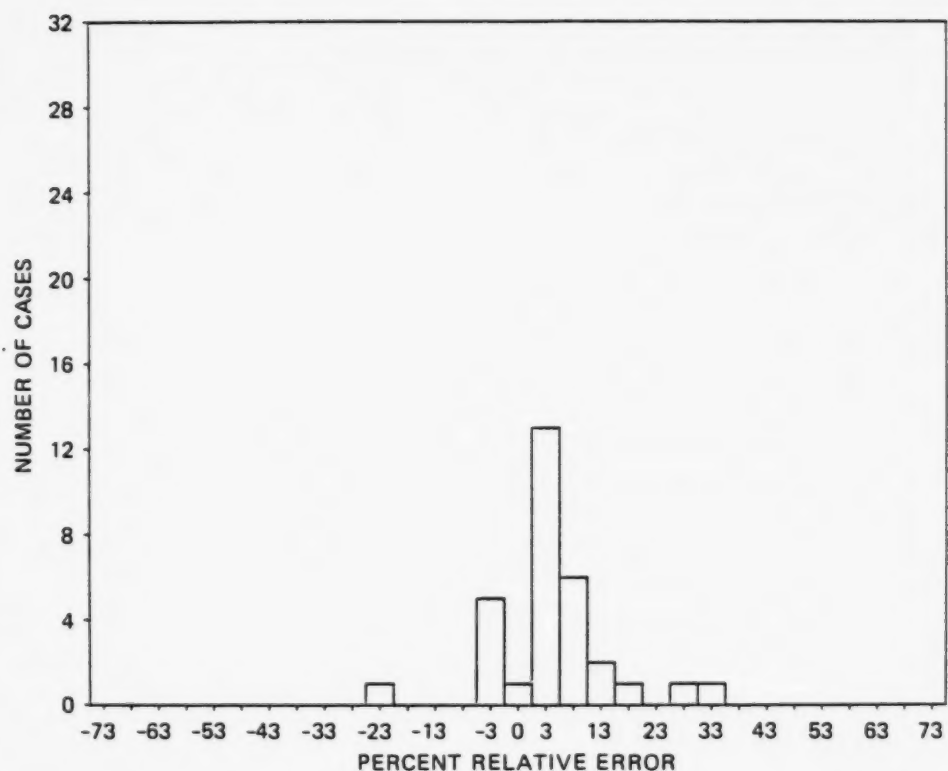
The CH_4 audits indicate that the accuracy of the measurements was probably generally good, the audits indicating relative errors of magnitude no greater than 20% occurring between 80% and 90% of the time.

In contrast to the CH_4 audits, checks of THC instruments revealed several large errors. This is evident in Figures 14 and 15, which show histograms of percent relative error for the EPA and RTI audits, respectively. The figures show that both data sets exhibit a tendency toward a positive bias.

The EPA audits (Figure 14) form two clusters, one with errors in the range -15% to +20%, and the other with errors exceeding +45%. The cluster

Table 13
STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR CO MEASUREMENTS

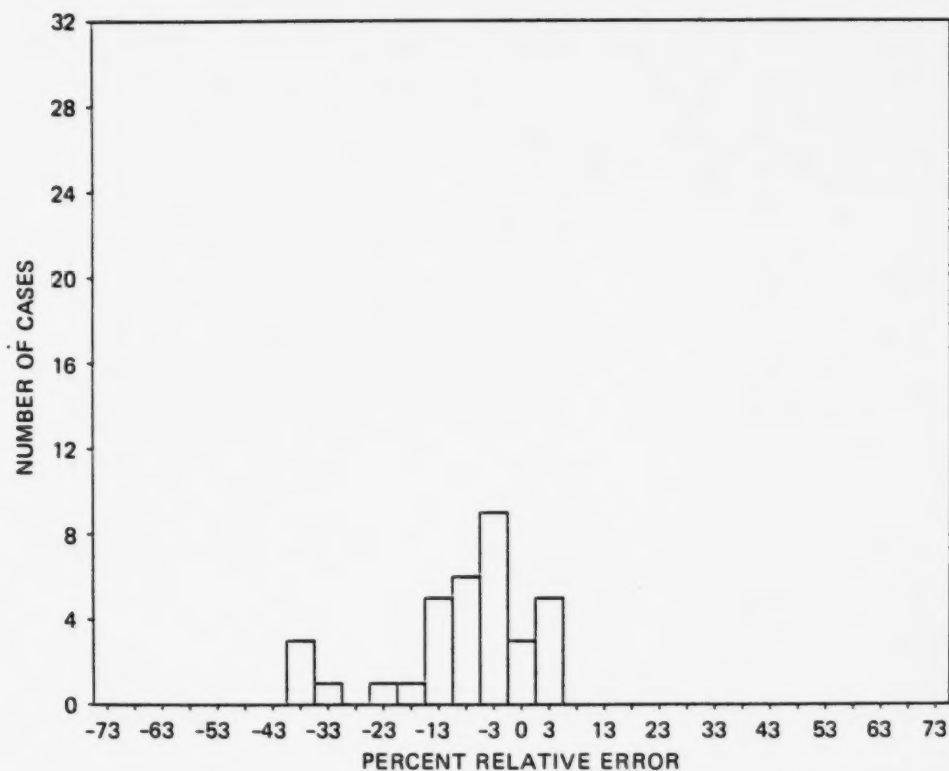
<u>Statistic</u>	<u>Audit Agency</u>	
	<u>EPA</u>	<u>RTI</u>
Mean	5.4	-5.3
Standard deviation	14.9	24.7
Median	4.0	-4.0
Percent of audits within <u>+10%</u> error band	64.5	38.0
Percent of audits within <u>+20%</u> error band	74.2	62.0
Percent of audits within <u>+30%</u> error band	96.8	82.0



HA-7938-12

FIGURE 12 HISTOGRAM OF PERCENT RELATIVE ERRORS FOR EPA AUDITS OF METHANE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



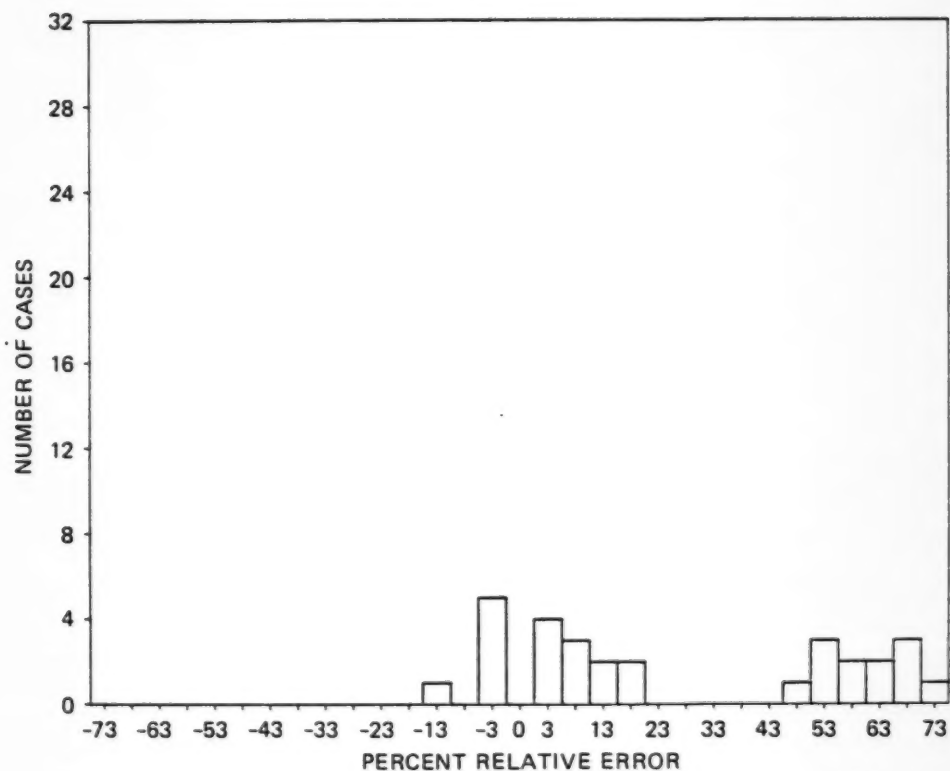
HA-7938-13

FIGURE 13 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF METHANE

Bar labeled 0 denoted cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

Table 14
STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR CH₄ MEASUREMENTS

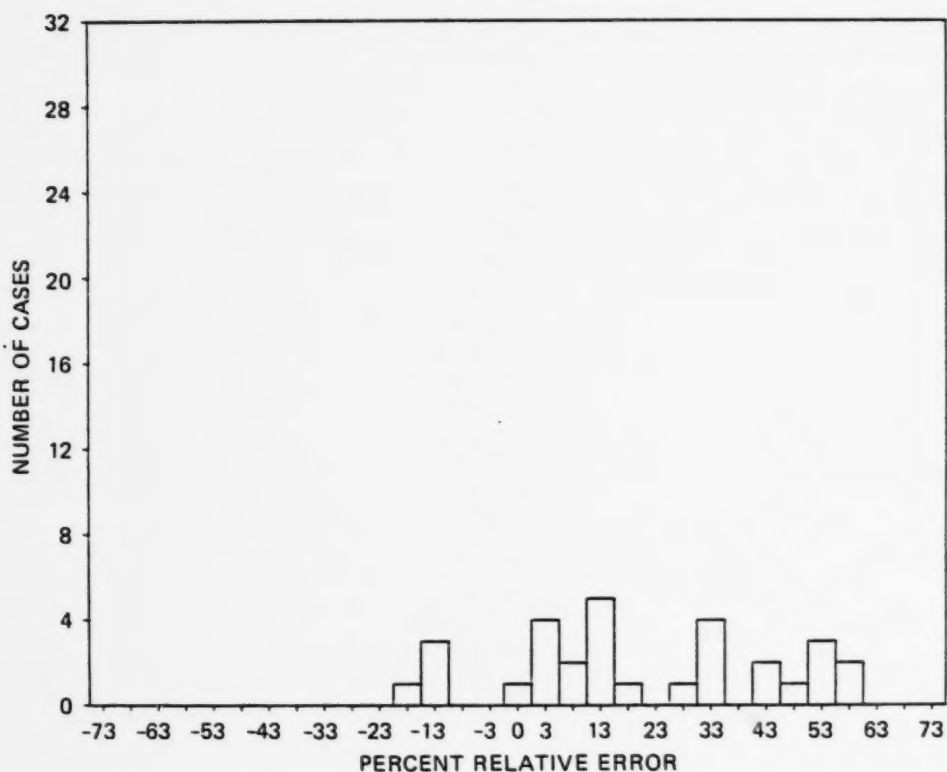
<u>Statistic</u>	<u>Audit Agency</u>	
	<u>EPA</u>	<u>RTI</u>
Mean	5.1	-9.2
Standard deviation	9.5	11.6
Median	4.0	-6.0
Percent of audits within <u>+10%</u> error band	80.6	67.6
Percent of audits within <u>+20%</u> error band	90.3	85.3
Percent of audits within <u>+30%</u> error band	96.8	88.2



HA-7938-14

FIGURE 14 HISTOGRAM OF PERCENT RELATIVE ERROR FOR EPA AUDITS OF TOTAL HYDROCARBONS

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.



HA-7938-15

FIGURE 15 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF TOTAL HYDROCARBONS

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

of large positive errors included 12 cases with values ranging from 50% to 72%. The 12 cases correspond to the instruments at Crawford, Parkhurst, and Clinton. The RTI audits of these same instruments, not performed on the same day as the EPA audits, also detected positive errors ranging from 27% to 114% at Crawford, from 33% to 43% at Parkhurst, and from 53% to 78% at Clinton. These errors form the rightmost cluster in Figure 15. Thus, the accuracy of THC data at these three sites is questionable.

Table 15 shows the statistics of the error distribution for THC. The tendency toward a positive bias is reflected in the values of mean and median. It is evident from the table that only between 50% and 60% of the measurements fall within the $\pm 20\%$ error band.

The THC audits indicate a tendency toward the occurrence of large positive errors at some instruments. This contrasts with the CH_4 data, which were generally accurate. Because nonmethane hydrocarbons (NMHC) are calculated by difference from $\text{NMHC} = \text{THC} - \text{CH}_4$, we have a situation in which the THC measurement may be inaccurate but the CH_4 observation is accurate. This, of course, renders the NMHC inaccurate. Particularly troublesome is the fact that the three instruments with the largest THC errors were located at Crawford, Parkhurst, and Clinton. These are urban/industrial sites that are supposed to characterize the hydrocarbon levels in central Houston. The audits suggest that hydrocarbon data from these sites need to be carefully scrutinized to establish their validity.

Sulfur Dioxide

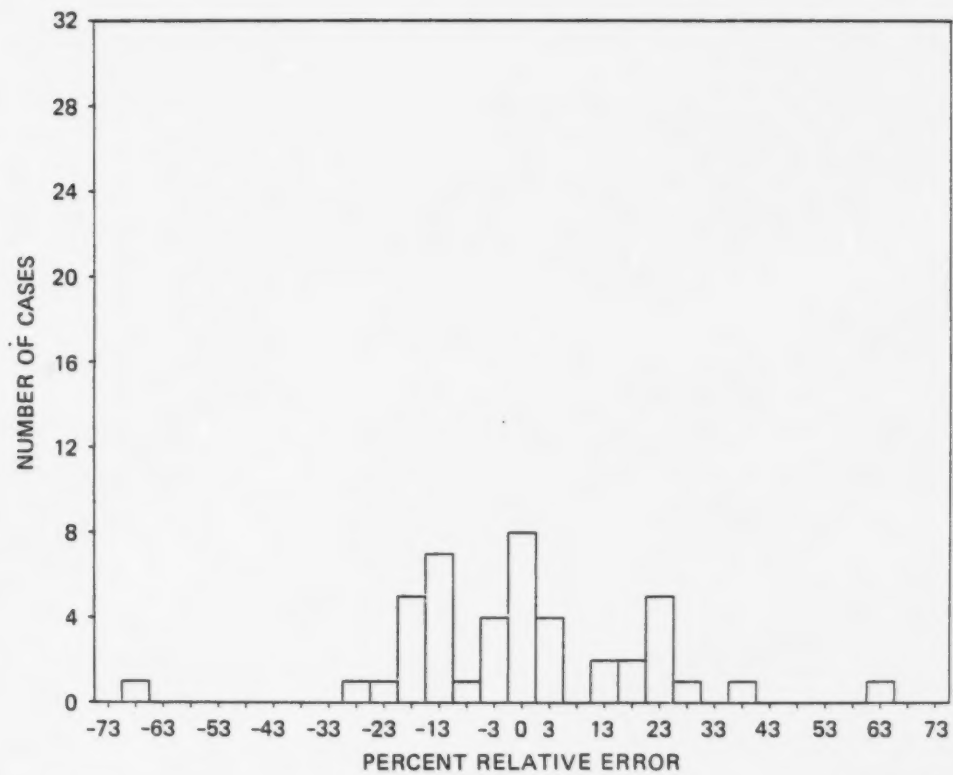
SO_2 instruments were audited only by RTI. Figure 16 shows a histogram of percent relative error for these audits. The figure shows several cases with large errors, but the bulk of the cases are clustered about zero.

The two large errors were -70% and $+65\%$, and occurred at Aldine and Pasadena, respectively. The other Aldine audits had values ranging from -28% to $+38\%$. The error of -70% was associated with the lowest nonzero reference concentration of 0.1 ppm, for which the instrument recorded 0.03 ppm. For Pasadena, the 65% error was also associated with the lowest nonzero reference, in this case 0.049 ppm, for which the instrument recorded 0.081 ppm. Other audit points at Pasadena had errors ranging from -15% to $+13\%$. Hence, in both cases, the large errors appear to be associated with sensitivity problems at the low end of the concentration range. (Zero-drift can be ruled out because a reference concentration of zero yielded a zero reading.)

The statistics of the error distribution are shown in Table 16. The mean error is near zero, and the median error is zero. Clearly, a large majority of the measurements fall within the $\pm 20\%$ error band.

Table 15
STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR THC MEASUREMENTS

<u>Statistic</u>	<u>Audit Agency</u>	
	<u>EPA</u>	<u>RTI</u>
Mean	26.5	26.1
Standard deviation	28.8	29.3
Median	15.0	15.0
Percent of audits within <u>+10%</u> error band	45.2	21.9
Percent of audits within <u>+20%</u> error band	61.3	53.1
Percent of audits within <u>+30%</u> error band	61.3	56.3



HA-7938-16

FIGURE 16 HISTOGRAM OF PERCENT RELATIVE ERROR FOR RTI AUDITS OF SULFUR DIOXIDE

Bar labeled 0 denotes cases with zero error. Other bars correspond to 5-percent error intervals, the label being the midpoint of the interval, e.g., 3 is the midpoint of the interval 1 to 5 percent.

Table 16

STATISTICS OF THE DISTRIBUTION OF PERCENT
RELATIVE ERROR FOR SO₂ INSTRUMENTS AUDITED BY RTI

<u>Statistic</u>	<u>Value</u>
Mean	-0.11
Standard deviation	21.0
Median	0.0
Percent of audits within <u>+10%</u> error band	38.6
Percent of audits within <u>+20%</u> error band	75.0
Percent of audits within <u>+30%</u> error band	88.6

REGRESSION ANALYSIS

Introduction

Whereas the previous analysis examined the audits in the aggregate, the present investigation considers each instrument individually. Specifically, we will derive linear regression equations relating the measured and reference concentrations. The equations have the form $y = Ax + B$, where y denotes the measured concentration, x represents the reference concentration, A is the slope, and B is the intercept.

Several factors are of interest in this analysis. First is the degree of linear correlation between y and x . Because the relationship between y and x should be linear, we would like to have the correlation coefficient approach unity.

Two other factors of interest are the slope and intercept of the regression equation. Ideally, the slope should be equal to one, which would indicate that there is no bias in the measurements. A slope greater than one indicates that the instrument's response is higher than the reference concentration, hence the instrument has a positive bias. Conversely, a slope smaller than one is indicative of a negative bias. A nonzero intercept is indicative of a zero-drift in the instrument's response. Under ideal conditions, the intercept should be zero. However, random errors in the instrument's response and in the value of the reference concentration will generally result in a nonzero intercept. In this case, the best result we can hope for is that the intercept will be small and statistically indistinguishable from zero.

Associated with the regression equation is its standard error, which reflects the amount of scatter about the regression. The standard error is an indicator of the instrument's precision.

In what follows, the measured O_3 , NO , NO_x , and NO_2 concentrations in the audits of the Jackrabbit instruments have been adjusted to correct the scaling error previously mentioned.

Ozone

Table 17 shows, for both the EPA and RTI audits, the correlation coefficient and the slope, intercept, and standard error of the regression equation for each instrument audited.

The EPA audits show that there is a very good linear relationship between measured and reference values, as evidenced by the correlation coefficients being close to unity. The slopes range from 0.391 to 1.162. The instruments at Pasadena, Channelview, and Seabrooke show substantial negative bias, their respective slopes being 0.685, 0.391, and 0.676.

Five instruments audited by EPA show small positive zero-drifts: Crawford, Channelview, Seabrooke, Jackrabbit, and the WSU aircraft. The

Table 17

REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF OZONE INSTRUMENTS

Location/ Instrument	EPA				RTI					
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ MEC 1100	0.9705	1.036	0.0051**	0.039	10 ⁺⁺	0.9996	1.322	0.0195**	0.015	6
Mae Drive/ MEC 1100	0.9988	0.913	0.0015**	0.007	10 ⁺⁺	0.9998	1.041	-0.0027**	0.008	6
Crawford/ MEC 1100	0.9999	1.115	0.0061	0.002	5	0.9999	1.217	0.0002**	0.003	6
Clinton/ MEC 1100	0.9953	1.162	0.0014**	0.017	10 ⁺⁺	0.9992	1.292	-0.0077**	0.007	6
Parkhurst/ MEC 1100	0.9919	0.972	0.0018**	0.020	10 ⁺⁺	0.9999	1.026	0.0007**	0.001	6
Lang/ MEC 1100	0.9918	0.841	0.0059**	0.016	9	0.9993	1.023	0.0032**	0.007	5
Darlinghurst/ CSI 2000	0.9768	0.940	0.0001**	0.032	10 ⁺⁺	0.9998	1.021	-0.0009**	0.004	6
Fuqua/ MEC 1100	0.9995	1.081	-0.0016**	0.006	5	0.9995	1.024	0.0060	0.005	6
Hornwood/ Bendix 8002	0.9995	0.938	-0.0014**	0.005	5	0.9992	1.082	-0.0041**	0.008	6
Pasadena/ Bendix 8002	0.9961	0.685	0.0028**	0.006	10 ⁺⁺	0.9989	0.773	0.0124	0.003	6
Channelview/ Bendix 8002	0.9995	0.391	0.0072	0.002	5	0.9980	0.532	0.0020	0.003	6
Seabrooke/ Bendix 8002	0.9995	0.676	0.0110	0.002	5	0.9996	0.684	0.0017	0.001	6
Westholllow/ MEC 1100	--+	--	--	--	--	0.9992	0.962	0.0143	0.006	6
Westholllow DASIB1 1003AH	--+	--	--	--	--	0.9999	1.007	0.0069**	0.003	6

Table 17 (concluded)

Location/ Instrument	EPA				Number of Points	RTI				
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)		Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Beasley/Monitor Labs 8410	0.9992	0.951	0.0058**	0.006	10 ⁺⁺	0.9997	1.132	-0.0037**	0.005	6
Pearland/ Bendix 8002	0.9970	0.997	0.0044**	0.006	10 ⁺⁺	0.9990	1.155	0.0047***	0.004	6
Sheldon/ CSI 2000	0.9959	1.026	-0.0015**	0.008	5	0.9976	1.045	0.0078**	0.005	6
Jackrabbitt/ Bendix 8002	0.9968	0.889	0.0054**	0.004	9 ⁺⁺	0.9994	1.005	-0.0042**	0.003	6
Radian Mobile Lab/ Metoy OA350	--+	--	--	--	--	0.9998	0.979	0.0048**	0.003	6
EPA Mobile Lab/ Bendix 8002	0.9998	0.884	0.0036**	0.003	5	0.9977	0.950	0.0054**	0.005	6
EPA Mobile Lab/ DASIBI 1003AH	--+	--	--	--	--	0.9990	1.057	-0.0106	0.008	7
WSU Aircraft/ Bendix 8002	0.9961	0.999	0.0140	0.007	5	0.9990	1.070	0.0020**	0.004	6

* Coefficients of regression line $y = Ax + B$, y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level.

+ Dashes denote no audit performed.

++ Pooled data for two separate audits

intercepts for these five instruments are statistically significant at the 0.05 level or better, and range from 0.0061 to 0.0140 ppm.

The EPA audits show that the precision of the instruments ranged from 0.002 to 0.020 ppm, as indicated by the standard errors in Table 17.

RTI's audits follow the pattern of the EPA's, showing very high linear correlations between measured and reference concentrations. The slopes range from 0.532 to 1.322. As in the EPA audits, the RTI data show substantial negative bias at Channelview (slope = 0.532) and Seabrooke (slope = 0.684) as well as statistically significant nonzero intercepts, which are indicative of positive zero-drift.

The RTI audits indicate the presence of positive bias at Aldine (slope = 1.322) and at Clinton (slope = 1.292). The EPA audits at these two sites show a smaller positive bias than the RTI audits. Excluding the two smallest and two largest slopes in the RTI data, the others range from 0.773 to 1.217, which correspond to biases ranging from -23% to +22%.

In the RTI audits six instruments show statistically significant nonzero intercepts: Fuqua, Pasadena, Channelview, Seabrooke, Westhollow, and the EPA Mobile Lab. These intercepts range from -0.0106 ppm to 0.0143 ppm. As indicated by the standard error in the RTI audits, instrument precision ranged from 0.001 ppm to 0.015 ppm, all but one of the standard errors being less than 0.010 ppm. Thus, precision appears to be reasonably good.

NO, NO_x, and NO₂

Table 18 shows the regressions for the NO audits. Both EPA and RTI audits exhibited high linear correlations for all but one of the instruments. The EPA audit of the Pearland instrument has a correlation coefficient of 0.7883, but for the RTI audit the coefficient is 0.9976. The EPA audit for Pearland has a lower correlation coefficient because it is composed of two separate audits of five points each. Each five-point audit showed a highly linear relationship between measurement and reference, but the two lines have different slopes that lower the linear correlation when the data are pooled. This suggests that problems may exist in the NO measurements at Pearland.

The slopes of all the NO audits ranged from 0.534 to 1.444. In most cases, the EPA audits show slopes consistent with the RTI audits. The EPA audits for Fuqua and Pearland show evidence of negative bias, having slopes of 0.534 and 0.660, respectively, whereas the RTI audits showed slopes slightly above 1.0 for both sites. The largest positive bias occurs at Parkhurst in the RTI audit, which has a slope of 1.444. However, this is inconsistent with the EPA audit of the same instrument, which showed a slope of 1.113. Both EPA and RTI indicate a negative bias at the Sheldon and WSU Aircraft instruments.

Only the RTI audits for NO detected evidence of zero-drift at the Radian Mobile Lab and EPA Mobile Lab. The NO instruments showed precision

Table 18
REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF NITRIC OXIDE INSTRUMENTS

Location/ Instrument	EPA				RTI					
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ TECO 14	0.9989	1.041	-0.0055**	0.009	10 ⁺⁺	0.9999	1.032	-0.0065**	0.005	6
Mae Drive/ TECO 14	0.9986	1.197	-0.0018**	0.013	10 ⁺⁺	0.9999	1.181	-0.0068**	0.006	6
Crawford/ TECO 14	0.9996	1.009	-0.0102**	0.006	5	0.9993	1.056	-0.0081**	0.007	6
Parkhurst/ Bendix 8101B	0.9753	1.113	0.013**	0.042	9 ⁺⁺	0.9995	1.444	-0.0075**	0.007	5
Lang/ Bendix 8101B	0.9924	1.001	0.0007**	0.018	10 ⁺⁺	0.9997	1.087	-0.0052**	0.005	6
Fuqua/ Bendix 8101B	0.9988	0.534	0.0014**	0.004	5	0.9998	1.041	-0.0010**	0.004	6
Pasadena/ CSI 1600	0.9971	1.208	-0.0210**	0.020	5	0.9993	1.080	-0.0076**	0.008	6
Channelview/ CSI 1600	0.9994	1.054	0.0066**	0.008	5	0.9995	1.035	-0.0019**	0.007	6
Seabrooke/Monitor Labs 8440	0.9993	0.935	0.0086**	0.005	5	0.9998	0.954	0.0014**	0.001	6
Westhollow/Monitor Labs 8440	--+	--	--	--	--	0.9998	0.974	0.0049**	0.003	6
Pearland/ TECO 14	0.7883	0.660	0.012**	0.040	10 ⁺⁺	0.9976	1.013	0.0009**	0.005	6
Sheldon/Monitor Labs 8440	0.9973	0.746	-0.0036**	0.004	5	0.9982	0.810	-0.0005**	0.004	6
Jackrabbit/Monitor Labs 8440	0.9996	0.995	0.0005**	0.004	9 ⁺⁺	0.9999	0.966	-0.0048**	0.001	6

Table 18 (concluded)

Location/ Instrument	EPA					RTI				
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Radian Mobile Lab/ CSI 1600	--†	--	--	--	--	0.9999	0.972	0.0042	0.002	6
EPA Mobile Lab/ CSI 1600	--†	--	--	--	--	0.9999	1.018	-0.0043	0.003	6
WSU Aircraft/ Bendix 8002	0.9938	0.771	0.0006**	0.002	5	0.9937	0.7987	-0.0037**	0.017	6

* Coefficients of regression line $y = Ax + B$, y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level.

† Dashes denote no audit performed.

++ Pooled data for two separate audits.

better than 0.010 ppm, except at Mae Drive, Parkhurst, Lang, Pasadena, and Pearland. In general, the precision of the RTI audits was better than that of the EPA audits.

Table 19 shows the regressions of the NO_x audits for both EPA and RTI. In contrast to NO , all the NO_x audits have correlation coefficients close to unity. The slopes range from 0.531 to 1.357. The EPA data show the Fuqua instrument has a slope of 0.531, indicating substantial negative bias; this was also the case for the NO data (Table 18). However, the RTI audit of this instrument shows very little bias for both NO_x and NO . The largest positive bias in the RTI data occurs at Parkhurst, where the slope is 1.357, but this is inconsistent with the EPA audit. Both EPA and RTI audits indicate a positive bias of over 20% at the Mae Drive site.

Although some intercepts are statistically different from zero, all the NO_x audits show very small zero-drift. Precision ranged from 0.002 ppm to 0.040 ppm, the largest value occurring at Parkhurst in the EPA audit.

The results for NO_2 are shown in Table 20. Both EPA and RTI audits show correlation coefficients approximating unity. The lowest was observed in the EPA audit at Pearland, where the value is 0.8564; this differs substantially from the value of 0.9996 in the RTI audit. The lower value is caused by the same phenomenon mentioned above in connection with the NO audit at Pearland.

As with NO and NO_x , the EPA audit for NO_2 shows that the Fuqua instrument has a large negative bias, having a slope of 0.536. However, the RTI audit shows the opposite, viz., a positive bias with a slope of 1.276. With the exception of Fuqua, the NO_2 slopes ranged from 0.767 to 1.228; hence accuracy can be characterized as ranging from -23% to +23%.

Five NO_2 audits showed statistically significant zero-drifts, viz., at Crawford, Pasadena, and Pearland for EPA, and at Aldine and Westhollow for RTI.

Instrument precision for NO_2 ranged from 0.001 to 0.032 ppm for both sets of audits. The largest standard error occurred at Pearland in the EPA audits, which differs by at least a factor of 10 from the precision indicated by the RTI audit of the same instrument.

Carbon Monoxide

Table 21 shows the regressions for CO . All the correlation coefficients are close to one. However, there are two anomalies, namely, the EPA audits for Parkhurst and Jackrabbit showed a correlation exactly equal to one, an occurrence which is highly unlikely in an experimental setting. Hence we will disregard these two audits in the discussion that follows.

The slopes of the regression lines ranged from 0.339 to 1.285. The slope of 0.339 indicates a substantial negative bias at the instrument in the EPA Mobile Lab. A slope of 0.614 was obtained for the RTI audit at

Table 19
REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF NO_x INSTRUMENTS

Location/ Instrument	EPA				Number of Points	RTI				
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)		Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ TECO 14	0.9992	1.139	-0.0066**	0.009	10 ⁺⁺	0.9999	1.127	-0.0062**	0.006	6
Mae Drive/ TECO 14	0.9997	1.285	-0.0005**	0.006	10 ⁺⁺	0.9999	1.236	-0.0064**	0.007	6
Crawford/ TECO 14	0.9998	1.014	-0.0082**	0.004	5	0.9993	1.064	-0.0092**	0.007	6
Parkhurst/ Bendix 8101B	0.9740	1.060	0.018**	0.040	8 ⁺⁺	0.9993	1.357	-0.0076**	0.008	6
Lang/ Bendix 8101B	0.9971	0.997	0.0031**	0.011	10 ⁺⁺	0.9998	1.047	-0.0092	0.004	6
Fugate/ Bendix 8101B	0.9992	0.531	0.0016**	0.004	5	0.9995	1.010	-0.0001**	0.006	6
Pasadena/ CSI 1600	0.9974	1.088	-0.018**	0.017	5	0.9995	0.973	-0.0056**	0.006	6
Channelview/ CSI 1600	0.9992	1.031	0.0078**	0.009	5	0.9995	1.033	-0.0031**	0.006	6
Seabrooke/Monitor Labs 8440	0.9998	0.877	0.0095	0.003	5	0.9995	0.962	-0.0001**	0.002	6
Westhollow/ Monitor Labs 8440	--+	--	--	--	--	0.9998	0.974	0.0049	0.003	6
Pearland/ TECO 14	0.9897	0.948	0.0071**	0.011	10 ⁺⁺	0.9984	1.016	0.0015**	0.004	6
Sheldon/Monitor Labs 8440	0.9996	0.785	-0.0005**	0.002	5	0.9996	0.751	-0.0039**	0.002	6
Jackrabbit/Monitor Labs 8440	0.9995	0.971	0.0006**	0.005	10 ⁺⁺	0.9999	0.972	0.0003**	0.002	6

Table 19 (concluded)

Location/ Instrument	EPA				RTI					
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Radian Mobile Lab/ CSI 1600	--+	--	--	--	--	0.9999	0.969	0.0051	0.003	6
EPA Mobile Lab/ CSI 1600	--+	--	--	--	--	0.9999	1.029	-0.0028	0.002	6
WSU Aircraft/Monitor Labs 8440	0.9910	0.802	0.0010**	0.002	5	0.9867	0.836	0.0345**	0.026	6

* Coefficients of regression line $y = Ax + B$, y = measured, z = reference, A = slope, B = Intercept.

** Not significant at the 0.05 level.

+ Dashes denote no audit performed.

++ Pooled data for two separate audits.

Table 20
REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF NO₂ INSTRUMENTS

Location/ Instrument	EPA				Number of Points	RTI				
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)		Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ TECO 14	0.9788	1.024	-0.0045**	0.028	10 ⁺⁺	0.9986	0.966	0.0286	0.020	6
Mae Drive/ TECO 14	0.9987	1.176	0.0066**	0.008	10 ⁺⁺	0.9996	1.036	0.0037**	0.011	6
Crawford/ TECO 14	0.9999	1.007	0.0051	0.002	5	0.9996	1.023	0.0010**	0.005	6
Parkhurst/ Bendix 8101B	0.9965	0.965	0.0024**	0.008	5	0.9997	0.790	0.0020**	0.002	5
Fuqua/ Bendix 8101B	0.9999	0.536	0.0012**	0.001	5	0.9998	1.276	0.0044**	0.004	6
Pasadena/ CSI 1600	0.9983	0.992	-0.0567	0.009	5	0.9958	0.897	-0.0222**	0.015	6
Channelview/ CSI 1600	0.9995	1.015	-0.0050**	0.005	5	0.9986	1.049	-0.0058**	0.004	6
Westhollow/ Monitor Labs 8440	--+	--	--	--	--	0.9998	1.028	0.0075	0.003	6

Table 2U (concluded)

Location/ Instrument	EPA					RTI				
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Pearland/ TECO 14	0.8564	0.767	0.0432	0.032	10 ⁺⁺	0.9996	0.998	-0.0016**	0.002	6
Sheldon/Monitor Labs 8440	0.9974	0.781	-0.0028**	0.003	5	0.9846	0.810	0.0025**	0.010	6
Jackrabbit/Monitor Labs 8440	0.9772	0.854	0.0145**	0.025	11 ⁺⁺	0.9999	0.966	0.0015**	0.002	8
Radian Mobile Lab/ CSI 1600	--+	--	--	--	--	0.9997	0.858	0.0044**	0.004	6
EPA Mobile Lab/ CSI 1600	--+	--	--	--	--	0.9996	1.001	0.0068**	0.005	6
WSU Aircraft/Monitor Labs 8440	0.9930	0.985	0.0011**	0.002	5	0.9864	0.895	0.0403**	0.028	6

* Coefficients of regression line $y = Ax + B$, y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level.

⁺ Dashes denote no audit performed.

⁺⁺ Pooled data for two separate audits.

Table 21
REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF CO INSTRUMENTS

Location/ Instrument	EPA				RTI					
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ Bendix 8200	0.9999	0.960	-0.4902**	0.203	4	0.9996	0.967	-0.4173**	0.449	8
Mae Drive/ Beckman 6800	0.9945	0.963	-1.0041**	1.611	7	0.9947	0.785	-0.1485**	1.356	8
Crawford/ Beckman 6800	0.9999	1.041	-0.4468**	0.326	4	0.9992	1.200	-0.3026**	0.383	6
Clinton/ Beckman 6800	0.9999	1.107	-1.0540	0.119	4	0.9995	0.953	0.5939	0.250	6
Parkhurst/ Beckman 6800	1.0000	1.084	-0.1004	0.0	4	0.9983	0.614	0.2884**	0.292	5
Westhollow/ Beckman 6800	--+	--	--	--	--	0.9996	0.942	-0.2154**	0.480	6
Pearland/ Beckman 6800	0.9997	1.285	0.374**	0.686	4	0.9983	1.149	0.3280**	0.226	5
Jackrabbitt/ Beckman 6800	1.0000	1.271	-0.4704	0.0	4	0.9989	1.161	0.2327**	0.214	6
EPA Mobile Lab/ Aeronutronics Philco/Ford	--+	--	--	--	--	0.9957	0.339	2.6415	0.554	7

* Coefficients of regression line $y = Ax + B$, y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level.

* Dashes denote no audit performed.

Parkhurst. Unfortunately, we cannot compare these two audits with the corresponding EPA audits. The largest slope of 1.285 was obtained for Pearland in the EPA audit, but it is higher than the slope of 1.149 in the RTI audit. Excluding the EPA Mobile Lab, Parkhurst and Pearland, the regression lines indicate that the accuracy of the CO instruments ranges from -22% to +20%.

Statistically significant nonzero intercepts ranging from -0.59 ppm to 2.6 ppm were detected at Mae Drive, Clinton, and the EPA Mobile Lab. The EPA audits show a negative intercept of about 1 ppm at Mae Drive and Clinton, which is inconsistent with the corresponding values obtained for the RTI audits. The positive intercept of 2.6 ppm obtained for the EPA Mobile Lab, together with the slope of 0.339, clearly indicate an accuracy problem for this instrument.

With one exception, the standard errors indicate that instrument precision was better than 1 ppm. The exception was Mae Drive, for which both EPA and RTI audits had standard errors of 1.6 ppm and 1.4 ppm, respectively.

Methane and Total Hydrocarbons

Table 22 contains the regressions for the CH₄ audits, and shows that all the correlation coefficients are close to one. The slopes range from 0.645 to 1.158. The value of 0.645 indicates a bias of about -35%, and was observed in the RTI audit of the Parkhurst instrument. However, the corresponding EPA audit has a slope of 1.026, indicating a very good accuracy. Excluding the slope of 0.645, the remaining slopes ranged from 0.850 to 1.158, indicating accuracies ranging from -15% to +16%. The precision was generally good, the standard errors ranging from 0.040 ppm to 0.278 ppm.

Only the Crawford instrument showed a significant zero-drift, both the EPA and RTI audits having an intercept of approximately -0.5 ppm.

The regressions for THC are shown in Table 23. As for CH₄, all the correlation coefficients are very close to one. However, in contrast to CH₄, several instruments showed substantial positive bias. Clinton and Parkhurst for both EPA and RTI audits, and Crawford in the EPA audits, showed the largest positive bias, with slopes ranging from 1.310 to 1.663, which correspond to accuracies of 31% and 66%, respectively.

Statistically significant zero-drifts were observed in the RTI audits for Aldine, Mae Drive, Crawford, and Clinton. Crawford has an intercept of about 2 ppm, which suggests a substantial inaccuracy. However, such a zero-drift does not appear in the EPA audit, in which the inaccuracy is reflected in the slope rather than in the intercept. If the audits indeed reflect normal operating conditions, then it follows that THC measurements at Crawford are of questionable accuracy.

Table 22
REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF CH₄ INSTRUMENTS

Location/ Instrument	EPA				RTI					
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ Beckman 6800	0.9997	1.063	-0.1512**	0.116	4	0.9994	0.988	-0.0797**	0.132	5
Mae Drive/ Beckman 6800	0.9991	1.012	-0.0500**	0.145	7	0.9997	0.951	-0.0374**	0.089	5
Crawford/ Beckman 6800	0.9997	1.158	-0.4795	0.130	4	0.9998	1.070	-0.5634	0.173	6
Clinton/ Beckman 6800	0.9999	1.033	0.2006**	0.171	4	0.9998	0.915	0.0946**	0.135	6
Parkhurst/ Beckman 6800	0.9997	1.026	0.0714**	0.104	4	0.9985	0.645	0.0447**	0.278	5
Pearland/ Beckman 6800	0.9993	1.025	0.1109**	0.171	4	0.9999	0.850	0.0350**	0.040	5
Jackrabbit/ Beckman 6800	0.9996	1.110	-0.1204**	0.141	4	0.9996	1.034	-0.1340**	0.115	6

* Coefficients of regression line $y = Ax + B$, y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level

Table 23
REGRESSION BETWEEN MEASURED AND REFERENCE CONCENTRATIONS FOR AUDITS OF THC INSTRUMENTS

Location/ Instrument	EPA				RTI					
	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points	Correlation Coefficient	Slope*	Intercept* (ppm)	Standard Error (ppm)	Number of Points
Aldine/ Beckman 6800	0.9998	1.081	-0.0002**	0.0001	4	0.9998	0.996	0.3654	0.068	5
Mae Drive/ Beckman 6800	0.9997	1.103	-0.0002**	0.0001	4	0.9999	0.990	0.3628	0.053	5
Crawford/ Beckman 6800	0.9997	1.549	-0.0866**	0.165	4	0.9975	1.196	1.9653	0.661	6
Clinton/ Beckman 6800	0.9988	1.634	-0.1411**	0.350	4	0.9999	1.513	0.4533	0.171	6
Parkhurst/ Beckman 6800	0.9997	1.663	0.0350**	0.176	4	0.9993	1.310	0.6396**	0.395	5
Pearland/ Beckman 6800	0.9996	0.992	-0.0706**	0.119	4	0.9998	0.839	0.0734**	0.052	5
Jackrabbit/ Beckman 6800	0.9997	1.194	-0.1333**	0.130	4	0.9999	1.141	0.0749**	0.071	6

* Coefficients of regression line $y = Ax + B$, y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level.

Sulfur Dioxide

Table 24 contains the regressions for the SO₂ audits conducted by RTI. All the correlation coefficients are very close to one. The accuracy, as indicated by the slope, for all but one instrument ranged from -18% to +19% which seems reasonable. The audit for the Aldine instrument has a slope of 1.420, indicating a positive bias of +42%.

No significant zero-drift was detected, and the precision ranged from 0.002 to 0.092 ppm.

Table 24

REGRESSION BETWEEN MEASURED AND REFERENCE
CONCENTRATIONS FOR RTI AUDITS OF SO₂ INSTRUMENTS

<u>Location/ Instrument</u>	<u>Correlation Coefficient</u>	<u>Slope*</u>	<u>Intercept* (ppm)</u>	<u>Standard Error (ppm)</u>	<u>Number of Points</u>
Aldine/ Bendix 5514548	0.9860	1.420	-0.1066**	0.092	6
Mae Drive/ Bendix 5514548	0.9987	1.189	-0.0129**	0.027	6
Clinton/ TECO 43	0.9996	1.023	-0.0031**	0.005	6
Pasadena/ Meloy SA-185	0.9928	0.822	0.0286**	0.021	6
Channelview/ Meloy SA-185	0.9929	1.096	0.0137**	0.025	6
Radian Mobile Lab/ Meloy 185	0.9999	0.870	-0.0027**	0.002	6
WSU Aircraft/ TECO 43	0.9997	0.831	0.0042**	0.004	8

* Coefficients of regression line $y = Ax + B$,
y = measured, x = reference, A = slope, B = intercept.

** Not significant at the 0.05 level.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The premise of an audit program is that random checks of an instrument can provide a good indication of the performance of that instrument. During the HOMS, most instruments were audited at least once but not more than twice by either EPA or RTI or both. Such an audit rate for individual instruments is too low to provide a data base from which to draw statistically valid conclusions regarding the overall performance of a particular instrument.

Because the audits were relatively few in number, the data were considered in two ways: by pooling all the audits for each type of instrument and by treating each instrument individually. Pooling the data enlarges the data base and allows general conclusions to be drawn about the overall quality of the data. Aggregating the audit data also helps to identify performance anomalies. By its nature, the results of the analysis of pooled audit data cannot be applied to specific instruments. Thus, we can make statements such as, "The audits indicate that about 70% of the measurements of pollutant X were accurate to within 20%." But we cannot state that 70% of the measurements of a specific instrument were accurate to within 20%.

Analyzing the audit performance of individual instruments can only serve either to assuage or raise doubts about the quality of the measurement of a given instrument. On the one hand, a good audit performance may cause us to feel confident about the instrument, recognizing, however, that this does not necessarily imply that all the measurements of that instrument are equally good. On the other hand, a poor audit performance raises doubts about the instrument, but again does not necessarily imply that other measurements are equally poor. Hence, one should consult historical calibration and repair records to obtain a better indication of whether the audit represents a persistent or a one-time condition. The results of this study provide guidance about the potential performance of individual instruments, but because the analysis is restricted to the audit data, this study cannot separate persistent conditions from one-time events. Each audit is a one-time event, and only many audits can fill in the picture.

CONCLUSIONS

Table 25 is a summary of the overall measurement accuracy for the various pollutants, based on the analysis of the pooled audit data. The table shows an estimated range for the percentage of the measurements that

Table 25
CHARACTERIZATION OF OVERALL MEASUREMENT ACCURACY

<u>Variable</u>	<u>Percent of Measurements Accurate to</u>		
	<u>+10 %</u>	<u>+20 %</u>	<u>+30 %</u>
Ozone	50-60	70-80	85-95
Nitric oxide	50-70	70-80	80-95
Nitrogen oxides	60-70	70-85	85-95
Nitrogen dioxide	45-55	70-75	80-90
Carbon monoxide	35-65	60-70	80-95
Methane	65-80	85-90	90-95
Total hydrocarbons	20-45	50-60	55-60
Sulfur dioxide	30-40	70-80	80-90

are accurate to within +10%, +20%, and +30%. For example, Table 25 shows that between 50% and 60% of the ozone data were accurate to within +20%, and 85% to 95% of the ozone data had errors bounded by +30%. Table 25 indicates that for ozone, NO, NO_x, NO₂, and SO₂, at least 70% of the data were accurate to within +20%. Methane has the largest fraction of the data accurate to within $\pm 20\%$. Carbon monoxide and THC can be considered to be the least accurate because they have the smallest fraction of the data in the +20% error band. The THC measurements were found to be subject to large inaccuracies, which explains the relatively low percentage of the data within the +30% error band. There is cause for concern about the quality of the continuous THC measurements and, hence, the continuous NMHC measurements in the HOMS. This representation does not necessarily apply to NMHC measurements made using discrete grab samples, since we did not analyze the quality of such data.

The regression analysis of individual instruments showed that almost all demonstrated exceptionally good linearity of response. The precision of the measurements, as indicated by the standard error of the regressions, was also good in nearly all cases. The accuracy, as reflected in the slope of the regression line, was variable. Specifically, the regression analyses indicated potential accuracy problems at the following monitoring sites:

- . O₃: Aldine, Pasadena,* Channelview,* Seabrooke*
- . NO: Parkhurst,* Fuqua,* Pearland*
- . NO_x: Mae Drive, Parkhurst,* Fuqua*
- . NO₂: Fuqua*
- . CO: Parkhurst, Pearland,* Jackrabbit,* EPA Mobile Lab*
- . CH₄: Parkhurst
- . THC: Crawford, Clinton, Parkhurst
- . SO₂: Aldine

All the instruments named above had regression lines whose slope was greater than 1.25 or smaller than 0.75 in at least one of the audits. The history of these instruments should be investigated to establish whether or not the bias was a recurring phenomenon. If the bias recurred, then it will be necessary to define correction factors to be applied to the routinely collected data. The preponderance of temporary instruments in the list suggests that such instruments may be more susceptible to misadjustment than the permanent monitors. Thus, in future programs using temporary instruments, special care must be taken to ensure proper operation of such instruments.

* Temporary instruments used only for the HOMS

RECOMMENDATIONS

Future monitoring programs should continue to include field audits of the instruments. However, the procedures followed should be changed to facilitate the interpretation of the audit data. In particular, the audit procedure should be designed to allow the analyst to draw statistically sound general inferences about the accuracy of individual instruments from the audit data. It was not possible to do so in this study because the number of audits was too small. Hence, it is recommended that future audit programs include in their design a determination of the number of audits required to describe the performance of individual instruments over the life of the monitoring program. This is a problem in statistical experiment design that is beyond the scope of our investigation.

Although it is desirable to have more than one agency conduct field audits, differences between EPA and RTI audit protocols produced some inconsistent results (e.g., EPA ozone audits showed a tendency toward underestimation, and RTI audits showed the opposite.) Thus, in this case procedural differences obscured the effects that the audits were intended to uncover. This situation should be avoided in future programs by having all parties adhere to a standard audit protocol.

The audit procedures used in the present program resulted in several cases of same-day audits of the same instruments by both EPA and RTI. Such overlap is desirable to check the consistency, or lack thereof, of the results obtained by the two auditing agencies. However, same-day audits of the same instrument essentially constitute a single audit, which acts to reduce the total number of tests. Future programs should ensure that overlapping audits do not lower the total number of checks performed.

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